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Low NO_x Heavy Fuel Combustor Concept Program

A. S. Novick and D. L. Troth
Detroit Diesel Allison Division
General Motors Corporation

October 1981

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-148

for
U.S. DEPARTMENT OF ENERGY
Fossil Energy
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NOTICE

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SUMMARY

This report documents the design of three and rig testing of two low-NO_x combustors resulting from DOE/NASA Contract DEN3-148, "Low-NO_x Heavy Fuel Combustor Concept Program." The objective of this program was to demonstrate in combustor rig hardware combustors which could operate at DDA Model 570-K engine conditions on middle distillate, residual, and synthetic fuels having a high percentage of fuel bound nitrogen, and achieve exhaust emission goals equal to or less than a 20 SAE smoke number and the maximum NO_x concentrations allowed by the EPA for industrial gas turbine engines. The NO_x goal for the middle distillate fuel was 50% of the maximum EPA NO_x level.

One of the combustor concepts was an air-staged combustor having a rich primary stage followed by a quick-quench mixer which diluted the fuel rich primary products for introduction to a fuel lean stage for final consumption of the fuel. The intent of this rich/quench/lean (RQL) combustor concept is to handle high viscosity fuel (residual) that may have high (greater than 0.5% by weight) fuel bound nitrogen (FBN) in a manner that suppresses the formation of NO_x emissions from both FBN and thermal (high temperature) sources.

The second combustor concept was designed as a fuel vaporizing addition between the RQL combustor fuel nozzle and rich zone. The vaporization section consisted of a preburner to supply adequate heat and a vaporizing section to completely vaporize the fuel. Beyond this point the combustor was the RQL combustor.

The third combustor was intended for use with fuels not having high levels of FBN. This concept was aimed at preventing thermally generated NO_x by utilizing a lean primary zone and a lean secondary zone, or a lean/lean (LL) combustor.

After a development test period to reduce air leakage to the rich primary zone, improve the rich primary zone cooling for better durability, and balance the fuel nozzle patternization, a series of performance tests was conducted on the RQL and LL combustors, and a series of parametric tests was conducted on the RQL combustor. Minimal time was spent on the LL combustor, as this type

combustor has successfully operated at DDA in the past. The new technology RQL combustor consumed the majority of the effort.

The RQL combustor demonstrated consistently low NO_x emissions (less than 55 ppmv corrected to 15% O_2) from all three fuels. These levels met or exceeded the contract goals of NO_x levels for minimum and maximum FBN fuels. The smoke goal of 20 SAE smoke number was easily met with measured smoke below 10. These minimum emissions were achieved at rich-zone equivalence ratios in the range of 1.25 to 1.40.

Parametric testing of the RQL combustor showed that the RQL combustor was essentially insensitive to the level of FBN at the minimum NO_x level of rich-zone equivalence ratio. NO_x variations with lean-zone equivalence ratio, rich-zone residence time, and overall combustor pressure drop were all documented. Exhaust smoke was consistently below an SAE smoke number of 20 at all conditions tested. The exhaust carbon monoxide and unburned hydrocarbon emissions were below 25 ppm by volume. Maximum combustor wall temperatures occurred in the fuel rich primary zone. The maximum measured metal temperatures were 1015 K (1621°F), 1170 K (1644°F), and 1110 K (1541°F) for middle distillate, residual, and synthetic fuels, respectively.

I. INTRODUCTION

Detroit Diesel Allison (DDA) is among five gas turbine engine manufacturers participating in the Department of Energy (DOE)/NASA Lewis Research Center (LeRC) "Low NO_x Heavy Fuel Combustor Concept Program" (Ref. 1). This combustor development program is part of the DOE/LeRC "Advanced Conversion Technology Project" (ACT).

At DDA, the objective of this technology generation program was to evolve a combustion technology base for a potentially durable, fuel-flexible combustor based on the operating conditions of the Allison Model 570-K, 4770 kW (6400 shp) industrial gas turbine engine. This combustor must be capable of sustained, environmentally acceptable "dry" operation on minimally processed heavy petroleum residuals, synthetic coal-derived liquids, and petroleum distillate fuels. From a fuel flexibility viewpoint, the advanced combustion technology developed under this DOE/LeRC program is essential to the future industrial engine market. Declines and uncertainties in the availability of petroleum distillate fuel and increasing demands for natural gas coupled with continually rising cost lead one to conclude that in the future industrial gas turbine users will require multifuel capability. Uninterrupted operation will be preserved as a result of fuel flexibility.

Fuels such as petroleum residuals or "synthetics" are most likely to become prominent for the utility and industrial user. Generally, these fuels have significant levels of bound nitrogen (FBN). In developing a fuel-flexible industrial engine combustion system the control of NO_x emissions from this pollutant source is a major challenge for the engine manufacturer. Consequently, significant technological advances from contemporary combustion systems are essential in order to operate gas turbine engines in an environmentally acceptable manner when using these fuels.

Because of general air pollution problems within the United States, the exhaust emissions from all fuel burning devices have been or are planned to be regulated by both Federal and State governments. Recently enacted Federal New Source Performance Standards (NSPS) regulations for stationary gas turbine engines (Ref. 2) specify pollutant emission concentration levels, which are below the current applied technology.

Pollutant emissions produced by gas turbines using petroleum distillate fuels are carbon monoxide (CO) and unburned hydrocarbons (UHC) at low power conditions, and oxides of nitrogen (thermal NO_x) at high power conditions.

Reductions of CO and UHC in contemporary combustors can be achieved by relatively straightforward approaches (Ref. 3,4). However, these approaches are subject to tradeoffs in operating range capabilities, combustion system complexities and control of thermal NO_x. The reduction of thermal NO_x is not as straightforward because the most favorable conditions for minimum NO_x are in opposition to combustion stability, production of CO and UHC, and operating range. Control of NO_x from FBN is less understood, but exploratory research (Ref. 5) indicates control can be effected through a rich (excess fuel) combustion process. The flexibility to operate with nonstandardized fuels presents performance problems apart from emissions. High viscosity makes atomization, vaporization, and distribution difficult tasks, thus necessitating innovative fuel injector design and development. Distillation variations, including the high distillation temperatures for residual fuel, require special consideration as related to combustor sizing. Reduced hydrogen content or high aromatics, especially for synthetics, presents a problem in the area of liner durability due to high radiation loads. In essence, all facets of combustor design and development require careful review and advancements when multifuel capability is the goal.

The DDA design rationale for multifuel capability is to inhibit NO_x formation from FBN in a rich burning zone and quickly and uniformly quench the exiting hot products so that a minimum of thermal NO_x will be formed in the final lean reaction zone. To accomplish this, a unique staged-air combustor has been developed. This combustor is referred to as the RQL combustor, signifying an initial rich-burning zone followed by a quench zone and a lean reaction and dilution zone.

Development of this combustor consisted of design, fabrication, and test over the engine operating range with three distinctively different fuels. This report contains all phases of this development effort including design criteria, test results, and conclusions relating to future engine application of this technology.

II. COMBUSTOR DESIGNS

Present diffusion flame combustors operating on aviation quality petroleum distillates (JP-4, JP-5, Jet-A, etc.) or industrial quality fuels (DF-1, DF-2, kerosene, etc.) produce significant levels of thermal NO_x due to the high temperatures created in regions having sufficient concentrations of fuel and atmospheric nitrogen (N_2) and oxygen (O_2). Reducing this thermal NO_x pollutant by controlling or reducing the reaction temperature is detrimental to operating range performance, combustion stability, and combustion efficiency (increased levels of CO and UHC).

As petroleum reserves dwindle, it is likely that utilities and industry will be required to operate on minimally processed petroleum residuals and/or synthetic fuels derived from coal or shale. These fuels contain, among other impurities, nitrogen-bearing compounds collectively called fuel bound nitrogen (FBN). At this time, the suppression mechanism of NO_x formation resulting from the combustion of fuels having significant FBN levels is not well understood, but indications are that NO_x suppression can be achieved by partially oxidizing the fuel in an oxygen deficient primary zone or rich zone. Since the overall combustion reaction is fuel lean, the difficult operation is the transition from the fuel-rich state to the fuel-lean state without permitting any meaningful oxidation time at or near stoichiometric fuel-air conditions. It is the quick-quench/rapid-mixing step that holds the key to a successful, low-NO_x, rich-to-lean, air-staged combustion process.

Liquid fuel flexibility for a low-NO_x combustor is a necessary requirement for any industrial or utility gas turbine engine. Therefore, in this program, three fuels were designated to be representative of the types of fuels that may be required for industrial/utility use.

- o A middle distillate petroleum fuel, ERBS
- o A petroleum residual fuel, RESID
- o A coal-derived liquid fuel, SRC-II

The low-NO_x combustor designs discussed in this section address the problems encountered in generating the combustion technology to satisfactorily burn middle distillate, residual, and coal-derived synthetic fuels that may contain high levels of FBN. In addition, the burning of these fuels must be accomplished in an environmentally acceptable manner, producing low-NO_x and smoke emissions.

DESIGN FEATURES

The objective of this program at DDA is to generate and demonstrate the technology necessary in developing a low-emission gas turbine combustor with the potential for durable operation in utility and industrial applications and the capability of operating on minimally processed petroleum residual or synthetic fuels. Also, the combustor technology should provide for operation on a wide variety of potential fuels, with varying properties, which might be available in the future.

Considering the three diverse test fuels, the combustors designed under this program were to demonstrate low NO_x and smoke emissions while providing combustion efficiencies above 99% in potentially durable engine applicable hardware. One concept was to achieve ultra-low NO_x and smoke when burning fuels having low levels of FBN. Another concept was to achieve low NO_x and smoke goals when burning fuels having moderate to high levels of FBN. It was deemed desirable to achieve these goals in a fuel-flexible combustion system. Although three concepts were investigated, the major emphasis was placed on a variable geometry combustor described in the following sections.

To minimize NO_x formation requires specific reaction zone stoichiometry. In general, oxides of nitrogen are formed when nitrogen in the atmosphere is subjected to high temperatures over a finite period of time in the presence of oxygen. The oxidation of atmospheric nitrogen can be minimized by operating at reaction zone temperature levels below approximately 1644 K (2500^{o}F). Unfortunately, in the excess oxygen state of lean combustion, FBN will still react to produce excessive levels of NO_x. It has been postulated and later demonstrated in fundamental experiments that a fuel rich combustion zone can

be effective in minimizing NO_x from FBN (Refs. 6,7). Therefore, two of the combustor concepts incorporated a fuel rich combustion zone for suppressing the NO_x formed from FBN. After successfully suppressing NO_x formation in the rich zone, an effective, quick and uniform quench is required for the transportation of the hot, rich mixture to the lean zone of the combustor where the balance of the fuel is oxidized. This rich/quench/lean process is diagrammed in Figure 1, which shows the two extreme paths for the quench transition from the rich stage to the lean stage. If the quench is rapid and uniform, the high temperatures and subsequent thermal NO_x that would result when the mixture passes slowly through stoichiometric conditions can be avoided.

The quenched mixture must next be oxidized to completion in a lean zone. Care must be taken in the lean zone to control the stoichiometry (temperature), which, with a proper volume (residence time), will complete the consumption of CO, UHC, and smoke without generating intolerable concentrations of thermal NO_x, thus negating the effects gained in the rich zone and the quick-quench mixer.

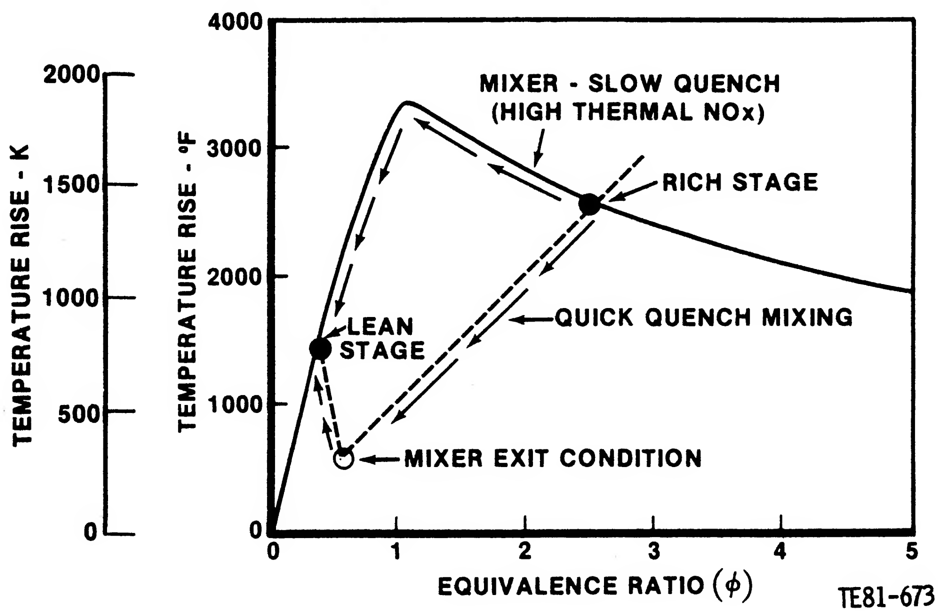


Figure 1. - Operational considerations for rich/quench/lean staged combustor.

The fundamental DDA design rationale is to inhibit NO_x formation from FBN in a rich-burning zone, and quickly and uniformly quench the exiting hot products so that a minimum of thermal NO_x will be formed in the final, lean reaction zone.

COMBUSTOR DESIGNS

Three variable geometry combustor concepts were devised to burn minimally processed or synthetic fuels while producing acceptably low levels of exhaust pollutants (CO, UHC, NO_x, and smoke). Combustor Concept I was devised to operate on fuels having high levels of FBN. This design was the RQL combustor. Combustor Concept II was designed expressly for accomplishing complete prevaporization of the heavy residual (RESID) fuel prior to entering an RQL combustor. A separate preburner and vaporizing volume were added at the main fuel injection point of the Concept I RQL combustor. Combustor Concept III was conceived to be a lean primary zone-lean oxidation zone (lean/lean) combustor, which would successfully operate with fuels having only minimal levels of FBN.

Following are descriptions and design features for each of the three program combustors.

Concept I--Rich/Quench/Lean (RQL) Combustor

The variable-geometry RQL combustor, shown in Figures 2 and 3, is composed of four basic components: fuel nozzle, rich combustion zone, quick-quench mixer, and lean combustion zone. (Each of these components is discussed in the following sections.) A schematic of the variable geometry RQL combustor is presented in Figure 4. Variable geometry controls the three major air injection areas in order to provide the capability to control reaction zone stoichiometry over the entire engine operating range.

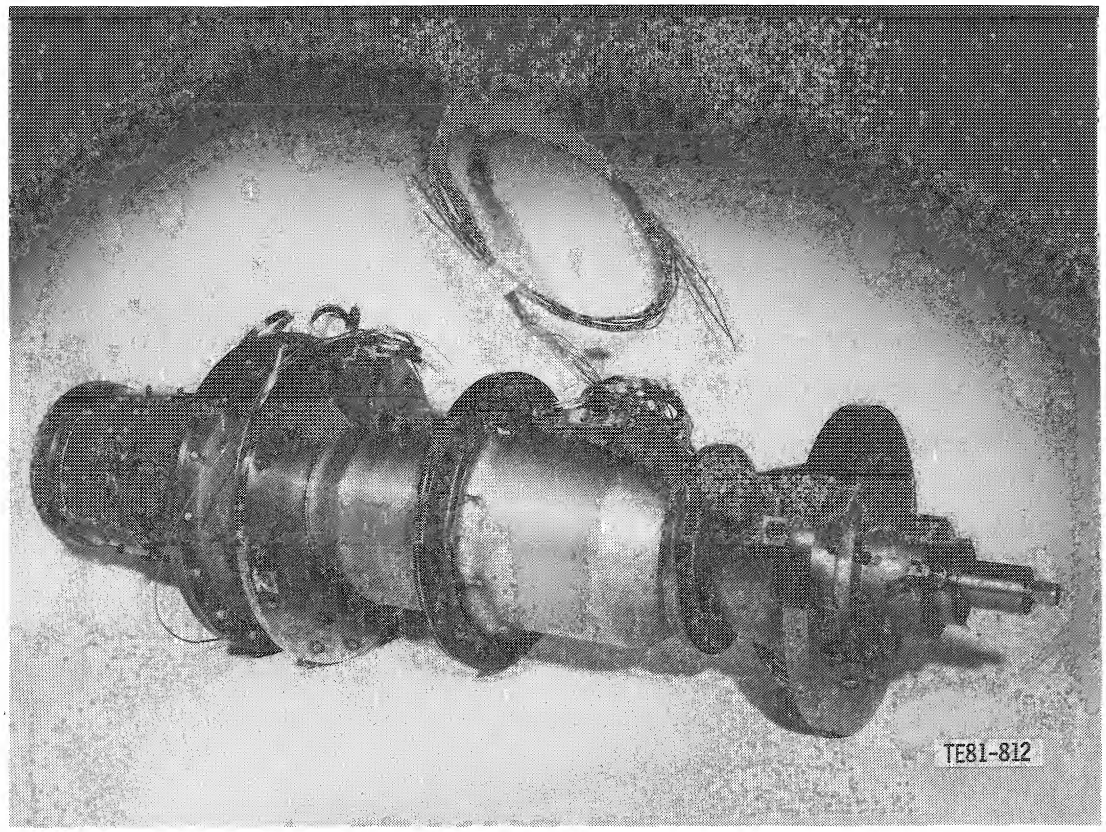


Figure 2. - Concept I--RQL combustor.

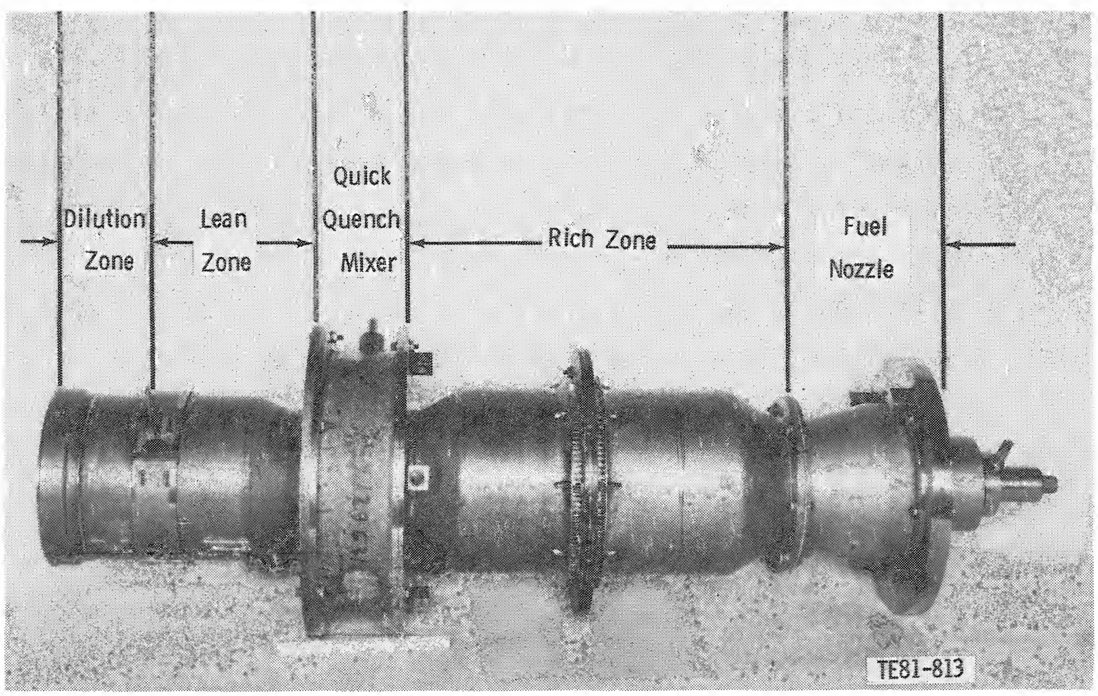


Figure 3. - Identification of RQL combustor components.

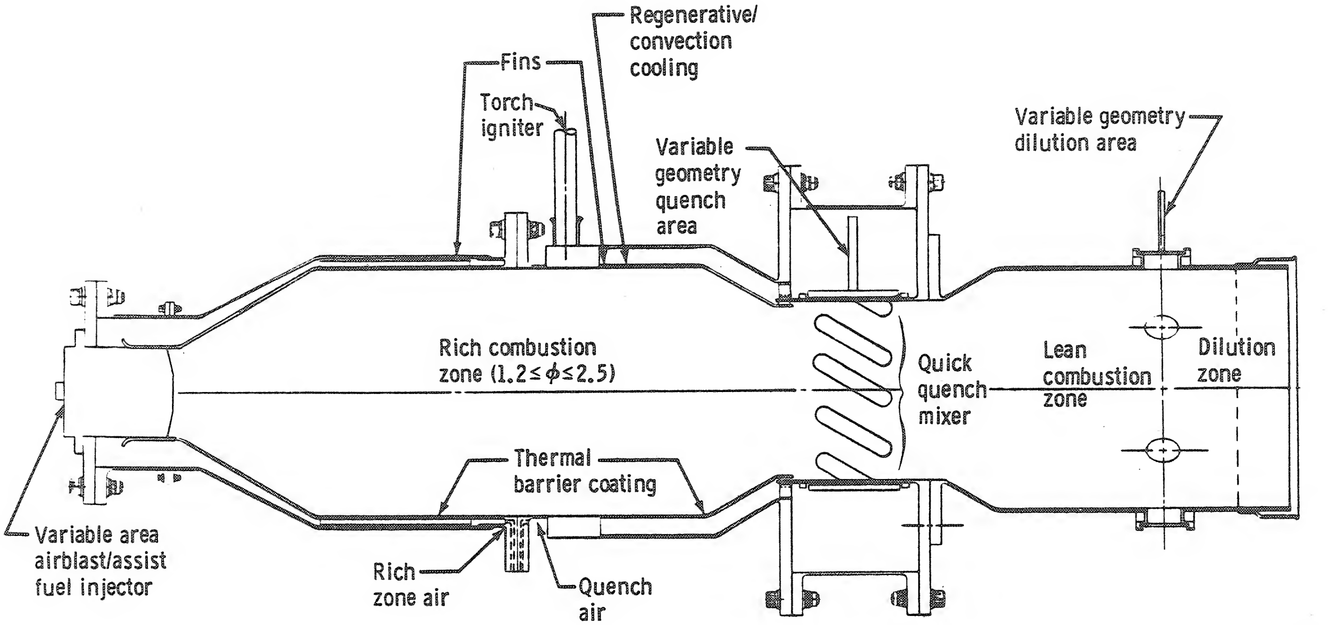


Figure 4. - Schematic of RQL combustor.

Fuel Nozzle

In the RLQ combustor all of the combustion air entering the rich zone flows through an air blast or air assist fuel nozzle where the air and fuel are premixed prior to entering the rich zone. In addition to producing a finely atomized and premixed fuel-air mixture, the swirling flow from the nozzle sets up the recirculation zone aerodynamics within the rich zone. There are no other air injection points into the rich zone because any air addition into the fuel rich reactant mixture would locally produce stoichiometric reactions and thus high levels of thermal NO_x and/or fuel nitrogen conversion to NO_x. An additional requirement of the fuel nozzle was that it be capable of varying the fuel-air ratio over the operating range so that the rich zone equivalence ratio could be varied from approximately 1.2 to 2.5 at a pressure drop of 6%.

To accomplish all of these operational requirements in an air blast type fuel nozzle the Gas Turbine Fuel Systems Division, Parker-Hannifin Corporation, was subcontracted. The resulting fuel nozzle is shown in Figure 5. It includes a fuel-prefilming air blast nozzle having a fixed air portion on either side of the fuel-filming surface and a much larger variable area radial inflow swirler downstream from the fixed swirler system. The variable area was accomplished

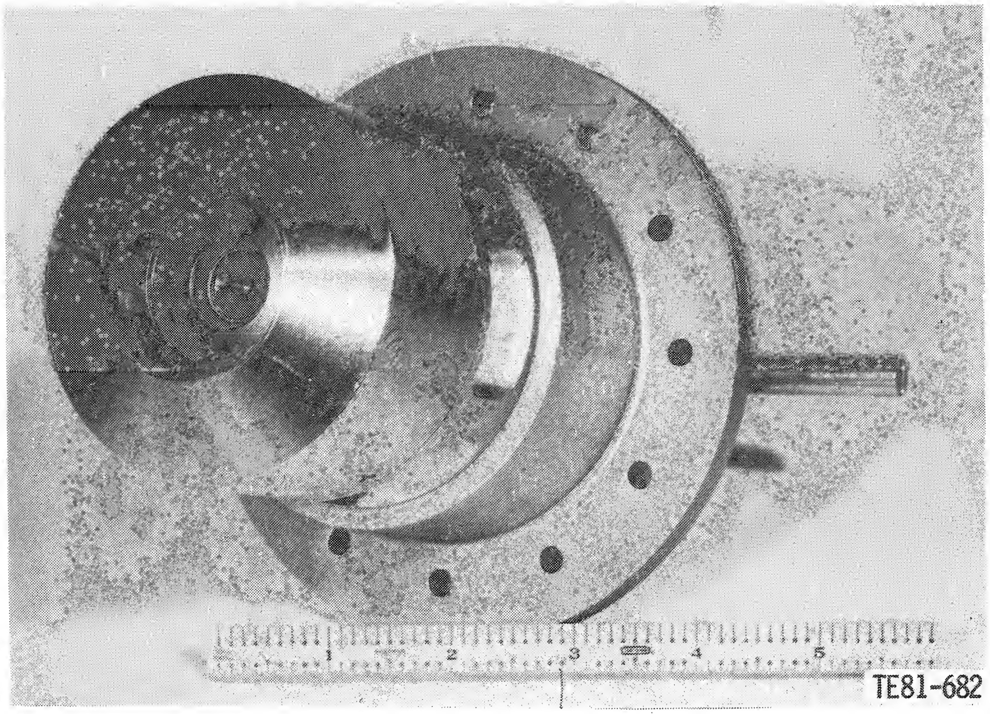


Figure 5. - Variable area, air blast fuel nozzle for RQL combustor.

by axially engaging two meshing sets of radial swirler vanes such that the air flow through these vanes varied from near zero, which produced a rich zone equivalence ratio of 2.5, to a maximum value, which would produce the 1.2 equivalence ratio in the rich zone. The photographs in Figure 6 show the nozzle at the two extremes in variable area: full open and full closed. In the closed position the air-fuel ratio of 3 is acceptable for good atomization quality. Results of ambient spray analysis tests conducted on the air blast nozzle are shown in Table I.

Initial experience with the air blast fuel nozzle in the RQL combustor revealed that because the nozzle was feeding a rich zone, no air leakage could be permitted along the barrel of the nozzle. Any such leakage air would remain near the wall of the combustor, resulting in stoichiometric burning along the rich zone dome and a critical operational and durability problem. The initial RQL combustor design incorporated a sliding seal along the fuel nozzle barrel to accept the thermal growth differential between the hot rich zone

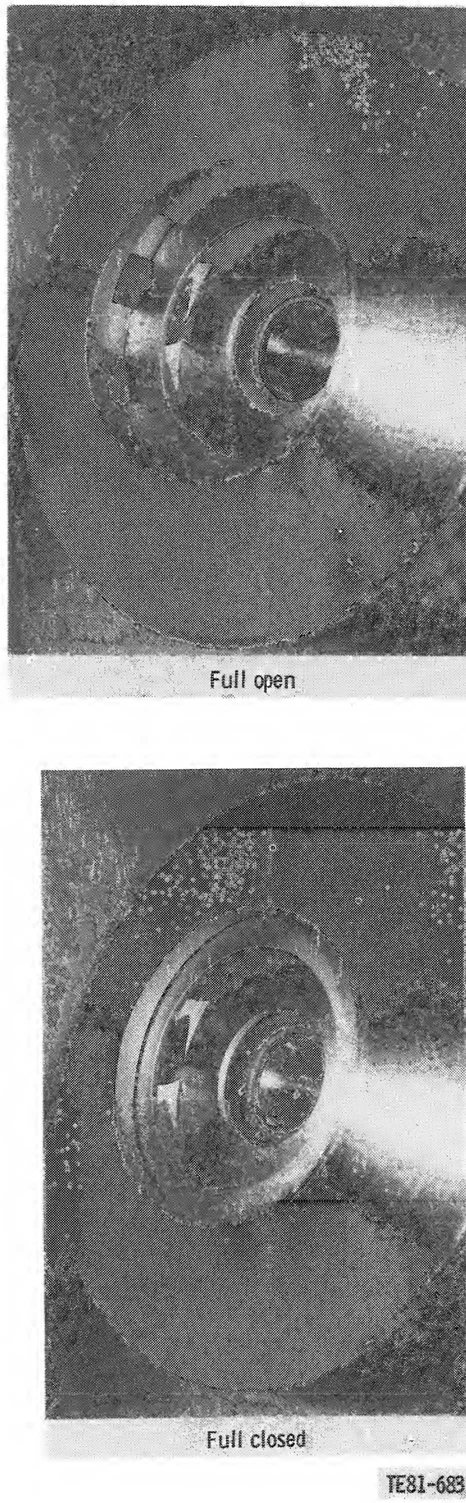


Figure 6. - Airblast fuel nozzle showing range in attainable variable area.

Table I.
Air blast fuel nozzle spray analysis summary (12 cs fluid).

Variable area position	Fuel flow-- g/s (pph)	Air, ΔP-- kPa (psi)	SMD-- microns
Closed	5.1 (40.8)	4.8 (0.7)	60
Closed	5.1 (40.8)	9.7 (1.4)	46
Closed	37.4 (297.0)	6.9 (1.0)	145
Closed	37.4 (297.0)	13.8 (2.0)	75
Half open	5.1 (40.8)	4.8 (0.7)	95
Half open	37.4 (297.0)	6.9 (1.0)	66
Full open	5.1 (40.8)	4.8 (0.7)	70
Full open	37.4 (297.0)	6.9 (1.0)	57

inner surface and the structural outer shell. The leakage problem was resolved by mounting a baffle to the rich zone inner surface at the entrance of the rich zone to act as a seal with the nozzle face and/or an air deflector for the leakage air, directing this air into the flow emanating from the fuel nozzle orifice.

The rich zone air passing through the variable area fuel nozzle doubled as cooling air for the forward portion of the rich zone. Because film-cooling air would cause stoichiometric burning of the fuel rich mixture along the rich zone walls, convection air cooling was used. The rich zone air was thus regenerated an additional 170°C (300°F) to a temperature of 795 K (961°F) at maximum continuous conditions before entering the fuel nozzle and rich zone. Air at this temperature, passing through the fuel nozzle, assists the fuel vaporization process but may cause binding of the variable area swirlers, especially when the vanes are fully meshed in the closed position. This remains a design problem area for any future hardware.

A variable area nozzle using an air-assisted pressure atomizer and an identical variable area swirler to the air blast nozzle was also designed. Atomization quality from this nozzle was not as satisfactory as the air blast, and minimal testing was done with this nozzle.

Rich Zone

One very important area in the design of the RQL combustor is the dimensional definition of the combustor rich zone flow path; i.e., diameter and length. Combustor diameter is interrelated to combustor throughput (reference) velocity. It is also dependent on the number of combustors that physically can be used in a can-annular combustion system. Time for vaporization of the fuel, especially important for the residual fuel, is, among other things, a direct function of the combustor length, i.e., residence time. Also, factored into the specification of a combustor volume is the geometric consideration for a flow recirculation/mixing pattern. With regard to the variable geometry RQL combustor, each zone must be sized based on the criteria for its operation.

The combustor's physical size was calculated for a can-annular combustion system with associated operating conditions (W_a, P and T), for the Allison Model 570-K engine operating at maximum continuous power. Rich zone residence time was determined under the assumption that fuel evaporation is the rate-controlling phenomenon. Inherent in the assumption is the fact that fuel-air mixing or reaction rates are not the limiting items. The analytical formulation for 100% vaporization is given by the following expression (Ref. 8).

$$\eta_c = 1.0 = 2.4 \left(\frac{\rho g}{\rho f}\right) \left(\frac{k}{Cp}\right)_g \ln (1 + B)_f \, V \left[\frac{Tu/100 \; f}{W_a \, A_L \, \mu_g \, D^3}\right]^{0.5}$$

where

η_c = vaporization fraction

ρ = density

k = thermal conductivity

Cp = specific heat

B = mass transfer number

V = rich zone volume

Tu = turbulence intensity percent (100 u'/U)

u' = rms value of fluctuating velocity

U = flow velocity

μ = viscosity

f = fraction of total air used in combustion

m = combustor mass flow

A_L = rich zone area

D = fuel droplet Sauter Mean Diameter (SMD)

Subscripts:

a = air

f = fuel

g = gas

substituting:

$$m_a = m_g = m_f \left[1 + \frac{1}{\phi_{RZ} f/a_{st}} \right]$$

$$Pr_g = \left(\frac{C_p \mu}{k} \right)_g \approx 0.65 \text{ (above 1050 K)}$$

with $\eta_c = 1.0$

$Tu/100 = 0.2$

$f = 1.0$

SpGr = specific gravity

and using the RQL combustor dimensions and operating conditions and solving for volume results in

$$V_{RZ} = 1.528 \; (10^{-9}) \left[\frac{SpGr}{\rho_g \ln (1+B)_f} \right] \left[(1 + \frac{1}{\phi_{RZ} f/a_{st}}) \frac{m_f D^3}{\mu_g} \right]^{0.5}$$

For a given volume

$$t = \frac{\rho_V}{m_g} = \frac{\rho_g V_{RZ}}{m_f \; (1 + \frac{1}{\phi_{RZ} f/a_{st}})}$$

Therefore the evaporation times for the RQL combustor can be computed from the expression

$$t = \frac{5.50\ (10^{-9})\ SpGr\ D^{1.5}}{\ln\ (1 + B)_f \left[(1 + \frac{1}{\phi_{RZ}\ f/a_{st}})\ m_f\ \mu_g\right]^{0.5}}$$

Vaporization times as a function of droplet diameter for the residual fuel are shown in Figure 7. Because the residual fuel required the highest temperatures and the longest vaporization times, the rich zone volume was sized for this fuel. There would thus be an excess of volume and residence time for both the ERBS and the SRC-II fuels.

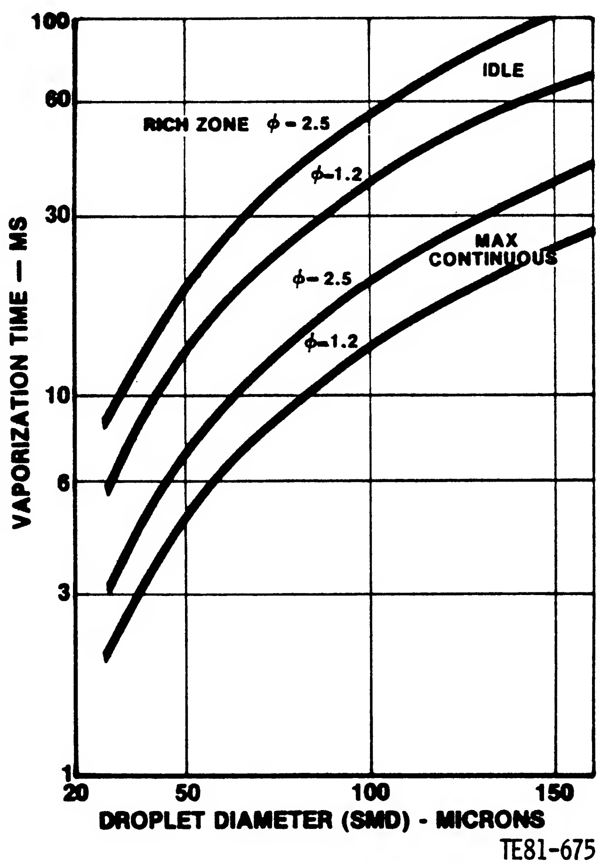


Figure 7. - Effect of atomization on RESID vaporization time.

Combustion stability limits and liner pressure drop were also factors considered in establishing a reference velocity. Rich combustion stability was of concern, because the concept was to partially oxidize a fuel rich mixture in the initial combustion zone. From a stability point of view, operational difficulties (Refs. 9-12) are generally associated with low pressure conditions such as are encountered in very high altitude aircraft operation; thus, no significant limitations were obvious for the operating range typical of the Allison Model 570-K industrial gas turbine engine. Based on current experience with the can-annular combustion system in Allison Model 501-K industrial engine, the pressure drop goal of 6% provides adequate mixing and air management and does not overly penalize engine performance. The reaction rate parameter (Ref. 13) was used to establish the lean combustion zone volume based on correlations with DDA engine operating experience on DF-2 fuel.

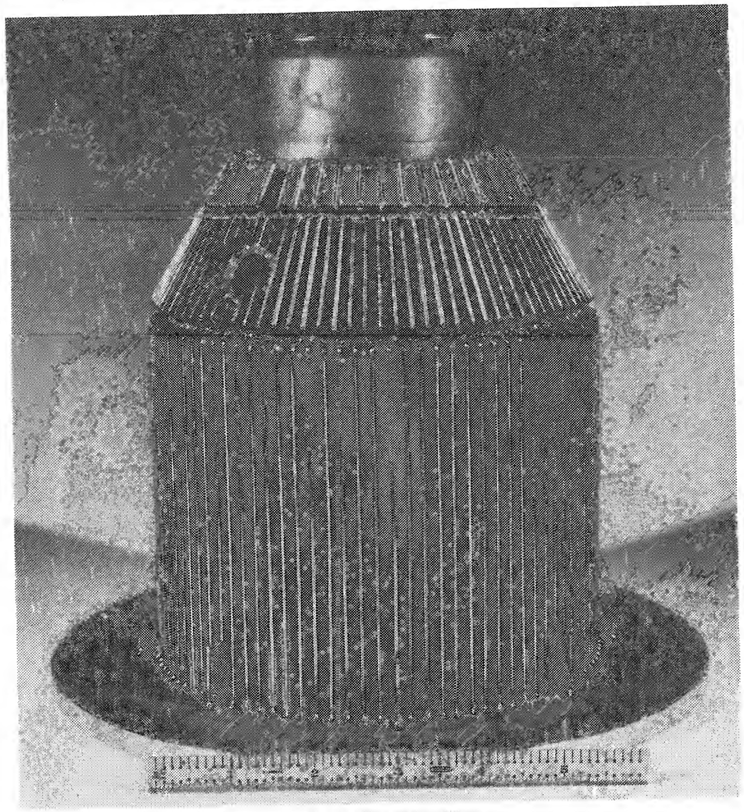
Based on the above criteria and engine size considerations, a combustion system of ten liners having a diameter of 140.5 mm (5.53 in.) was selected. The resulting reference velocity was 16.95 m/sec (55.6 ft/sec) at maximum continuous power operation. The combustion zone design lengths, compared to the calculated requirements for two rich zone equivalence ratios, are shown in Table II. A conservative estimate of an SMD of 100 microns at maximum power operation for residual was used in this design. Note that the length specification is set by the low power operating conditions and the equivalence ratio. This is due to the velocity variations in the rich zone as a consequence of operating conditions and air staging.

The design length provides for complete fuel vaporization over an anticipated range of droplet Sauter mean diameter (SMD) at all operating conditions except idle. Since idle is not a continuous operating condition for pollutant emissions, the compromise at this condition is reasonable. Also, sizing is directly dependent upon the atomizing performance of the fuel injector, and it was deemed prudent to concentrate on achieving better atomization at lower power than to provide increased combustor length at the potential expense of durability.

Table II.
Combustor size.

Design length requirement	Rich zone 27.94 cm (11.00 in.) Vaporization--cm (in.) ϕ = 1.8	ϕ = 1.3	Lean zone 13.97 cm (5.50 in.) Reaction, θ--cm (in.) ϕ =0.6
Max rated	20.91 (8.23)	26.11 (10.28)	7.04 (2.77)
Max continuous	20.83 (8.20)	26.01 (10.24)	9.19 (3.62)
70% power	21.13 (8.32)	26.42 (10.40)	11.00 (4.33)
50% power	21.72 (8.55)	27.18 (10.70)	13.77 (5.42)
Idle	22.74 (8.95)	28.55 (11.24)	21.26 (8.37)

If used, film cooling would produce copius amounts of thermal NO_x in the rich zone. Thus the rich zone was totally regenerative/convectively cooled. The air used to cool the forward portion of the rich zone becomes the rich zone reaction air, and the air cooling the aft portion of the rich zone becomes the quick-quench mixer air. Figure 8 shows the forward (upper photo) and aft sections of the augmented surface area (fins) rich zone hardware. The fins were attached by tack welding and brazing to ensure structural integrity and continuous surface contact, respectively. Due to space limitations, the number of fins on the forward section conical surface was reduced, and they were staggered to reinitialize the film boundary layer. A provision for the torch igniter can be seen on this conical surface. In addition to the augmented surface area, an LTB-8B thermal barrier coating produced by Linde Division of Union Carbide was applied to the inside surface of the rich and quench zones.



Forward section

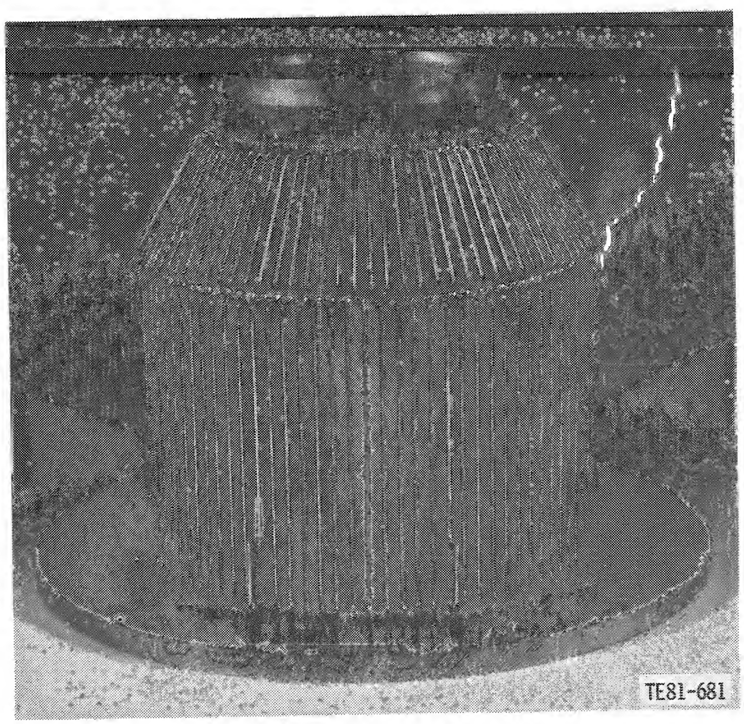


Figure 8. - Extended surface area forward/aft sections of rich stage.

The added thermal protection afforded by the coating was deemed especially desirable when using the SRC-II fuel with its low hydrogen content and consequently high radiation loads.

The initial design used ninety-six 7.6 mm (0.300 in.) high fins around the cylindrical portion of the rich zone. Ninety-six fins were also used on the aft cone and on the larger diameter portion of the forward cone. The forward section of the forward cone had forty-eight fins due to the reduced surface area. This configuration experienced limiting rich zone metal temperatures of 1340 K (1950°F) before rated combustor inlet temperatures could be achieved. Even though wall temperatures were closely monitored, minor damage to the forward rich zone hardware was experienced. Therefore, the forward rich zone was refabricated incorporating a series of changes intended to alleviate the high metal-temperature problem. A change was made in the rich zone metal thickness and material from 0.82 mm (0.032 in.) thick AMS-5536 (Hastelloy X) to 1.57 mm (0.062 in.) thick AMS-5608 (Haynes 188). Also, the height of the cooling fins was reduced from 7.62 mm (0.300 in.) to 5.08 mm (0.200 in.) to increase the Mach number past the cooling fins. The number of fins on the forward cone of the rich zone was increased from forty-eight to sixty-four, and the axial spacing between rows of fins was widened to 3.05 mm (0.120 in.) to ensure that staggering the rows of fins did not block passage exits. The initial location of the torch igniter was on the conical surface of the forward portion of the rich zone. This location required ferrules on both the flame tube cone and the outside support cone. It was determined that air leakage under the ferrules, in addition to blockage of the cooling air between the fins upstream of the torch igniter, contributed to the high metal temperatures observed in this region. Therefore the torch was moved from the rich zone dome to just aft of the rich zone center flange. In this position (see Figure 3) the cooling airflow was not blocked, and no leakage occurred around the torch igniter, as the torch was kept in contact with the bottom of the new ferrule due to the relative thermal differences between the combustor liner and the test rig outer case where it was mounted. Finally, an air-deflecting baffle was installed at the end of the fuel nozzle mounting tube to block air leaking into the rich zone past the fuel nozzle, and to divert any air that got by toward the center of the rich zone where it would be entrained in the swirling flow leaving the fuel nozzle. Subsequent testing produced rich zone metal temperatures consis-

tently below 1145 K (1600°F) and usually below 1090 K (1500°F), depending on the fuel. In addition to the reduction in the level of metal temperatures, the revised rich-zone design demonstrated considerably more uniform temperatures circumferentially at each axial station.

Quick Quench Mixer

Previous experience with rich/lean combustors clearly showed the sensitivity of the quench system and the care that must be taken to achieve quick, uniform, complete quench mixing of the hot rich zone products. A corporately funded dilution mixing experimental program (Ref. 14) gave insight into designing an adequate mixer. Warm air at 480 K (400^{O}F) flowed through a cylindrical chamber while 300 K (80^{O}F) air was injected through various geometrically arranged holes. The types of holes tested were circular holes, axial slots, inclined slots, and circular holes with turbulence generating bars. The number of holes was varied as well as the number of rows and configuration of holes. Each configuration maintained a constant effective area. Flows were varied to provide a range in momentum ratios (ratio of jet momentum to mainstream momentum) of 20 to 120.

Data reduction at four axial stations downstream of the dilution plane begins with the calculation of integrated average temperature, $T = \iint TdA/A$. Then a mass averaged equilibrium temperature is calculated by

$$T_{eq} = \frac{m_1 T_1 + m_2 T_2}{m_1 + m_2}$$

where subscripts 1 and 2 refer to the mainstream and injection air, respectively.

A nondimensional temperature that takes on positive and negative values is based on the equilibrium temperature and is given by

$$\phi = \frac{T - T_{eq}}{T_1 - T_{eq}}$$

where again T_1 is the mainstream temperature. Nondimensional temperatures are calculated for all radial and circumferential positions, and then the values are area averaged by

$$\bar{\phi} = \frac{\iint \phi \, dA}{A}$$

As a measure of the total deviation from thermal equilibrium, an integrated average is computed based on the absolute value of ϕ given by

$$|\bar{\phi}| = \frac{\iint |\phi| \, dA}{A}$$

The area weighted absolute value of ϕ becomes a measure of the relative "mixedness" and can be used to correlate data for different axial positions and different designs. The value of the integrated average $\bar{\phi}$ approaches zero as equilibrium or a completely mixed condition is reached.

A comparison of exit mixedness as a function of momentum ratio is shown in Figure 9. From this figure it can be seen that mixing degrades as momentum ratio increases for configurations of eight holes and eight slots, improves for configurations of sixteen holes and sixteen slots, and is relatively insensitive to a momentum ratio above 40 for circumferentially inclined slots. This is a result of penetration and jet interactions as a function of hole size. The interactions of the circumferentially inclined slots permit a portion of each jet to penetrate through the cylinder center line thus promoting more uniform mixing.

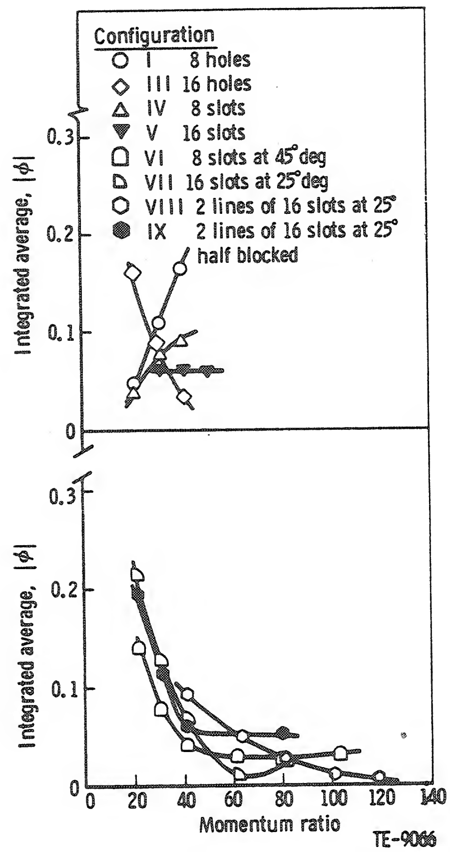


Figure 9. - Comparison of dilution configuration performance.

The result from this experimental study provided the basis for the design of the quick-quench mixer shown in Figure 10. The design consisted of two rows of twelve circumferentially inclined slots having a 4:1 aspect ratio (in the full open position).

The reduced diameter at the mixer forces the hot gas exiting from the rich zone to accelerate into the quench jets inhibiting any upstream mixing. It also provides for an expansion into the lean zone to initiate a stable combustion region. Inclining of the slots with respect to the axial direction serves a two-fold purpose. First, the arrangement results in more uniform mixing over a shorter length in comparison to conventional holes or slots. Second, the inclined slots contribute a tangential component of velocity to the hot rich zone combustion products near the wall, providing rapid expansion and flame stabilization in the lean zone.

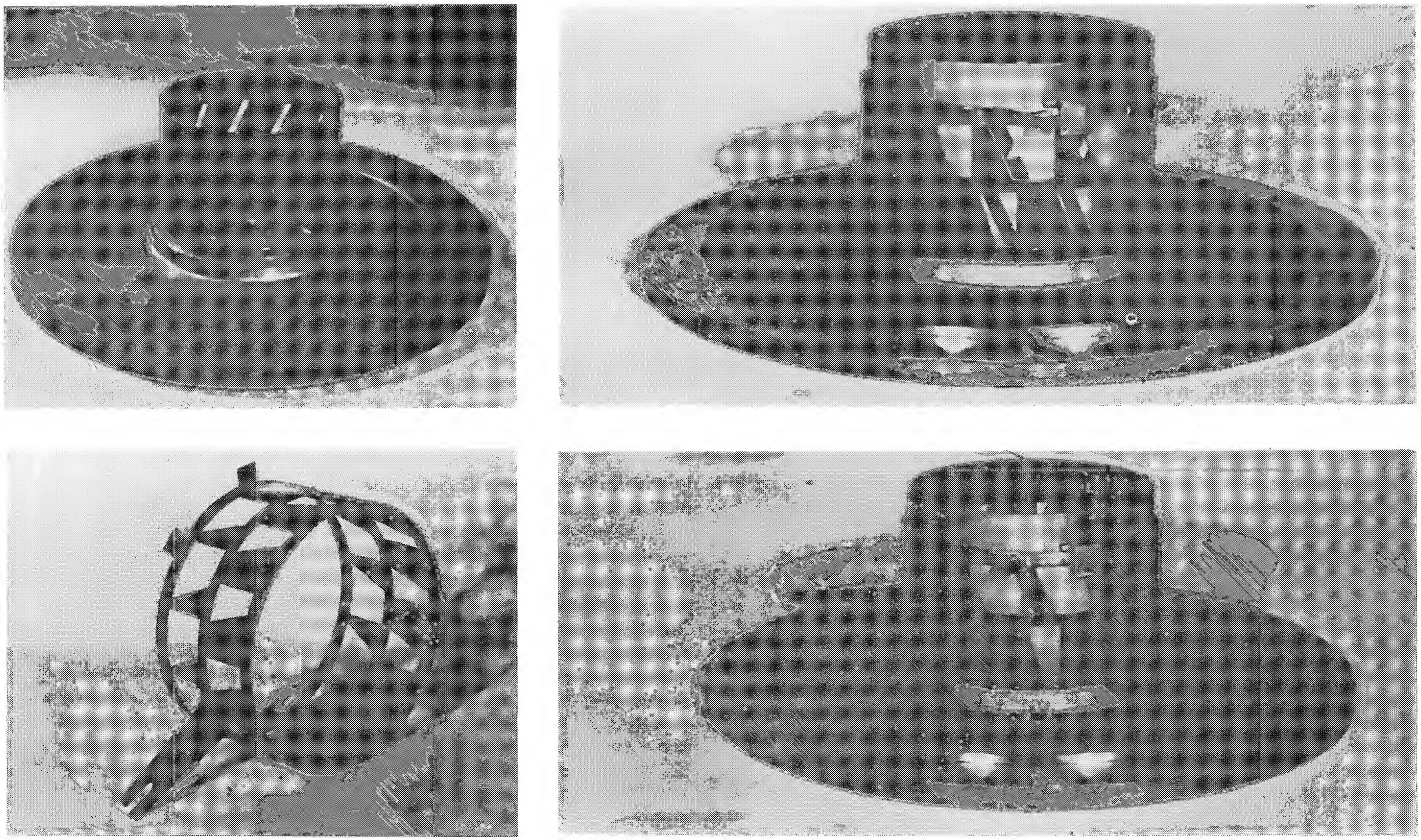


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Figure 10. - Variable area quick quench mixer.

As previously stated, the capability to uniformly and quickly quench the hot gas exiting the rich zone is essential. As the variable geometry RQL combustor is designed to operate over a range of rich and lean zone equivalence ratios of 1.2-2.5 and 0.4-0.6, respectively, the quench mixer must be capable of providing uniform transition between the two combustion zones over these equivalence ratio ranges. Two competing conditions arise regarding the quench phenomena. For a fixed lean zone equivalence ratio, increased quantities of quench air are required with increases in the rich zone equivalence ratio. This results in effective quench area increases at a fixed pressure drop. However, as the rich zone equivalence ratio increases, the quench jet momentum ratio (quench momentum/hot gas momentum) also increases due to the decrease in mass flow and temperature through the rich zone. These two conditions are in the direction of increasing jet penetration and thus nonoptimum mixing over a range of equivalence ratios. Also, in designing the quench mixer consideration was given to the fact that it must initiate a flow field in the lean zone conducive to stable combustion.

In addition to having a system of penetrating jets that will mix quickly with the rich zone flow, the mixing system also must be controllable and minimize area change sensitivities, especially when operating at small values of open area. To accomplish the required flow control, a rotating band was designed with openings specifically designed to provide smooth variations in mixing jet open area from full closed to full open. An asymetrical trapezoidal opening was used in the control band as shown in the sketch in Figure 11. As the axial edge (right side) of the opening begins to uncover the slot, the rate of area increases gradually to a fixed maximum due to the initial area being a triangle whose height and base are linearly increasing. Continued opening of the orifice produces a linear relationship of area with travel until the entire length of the slot is uncovered. At this point, the final triangle is opened, reducing the rate of area increase with travel. In the case of the RLQ combustor mixer, there are two rows of slots for which the slot and band openings are timed so that there is a smooth transition when the changes in area pass from the first row of slots to the second. Figure 11 shows how the idealized control band is rotated from "full closed" to "full open" positions.

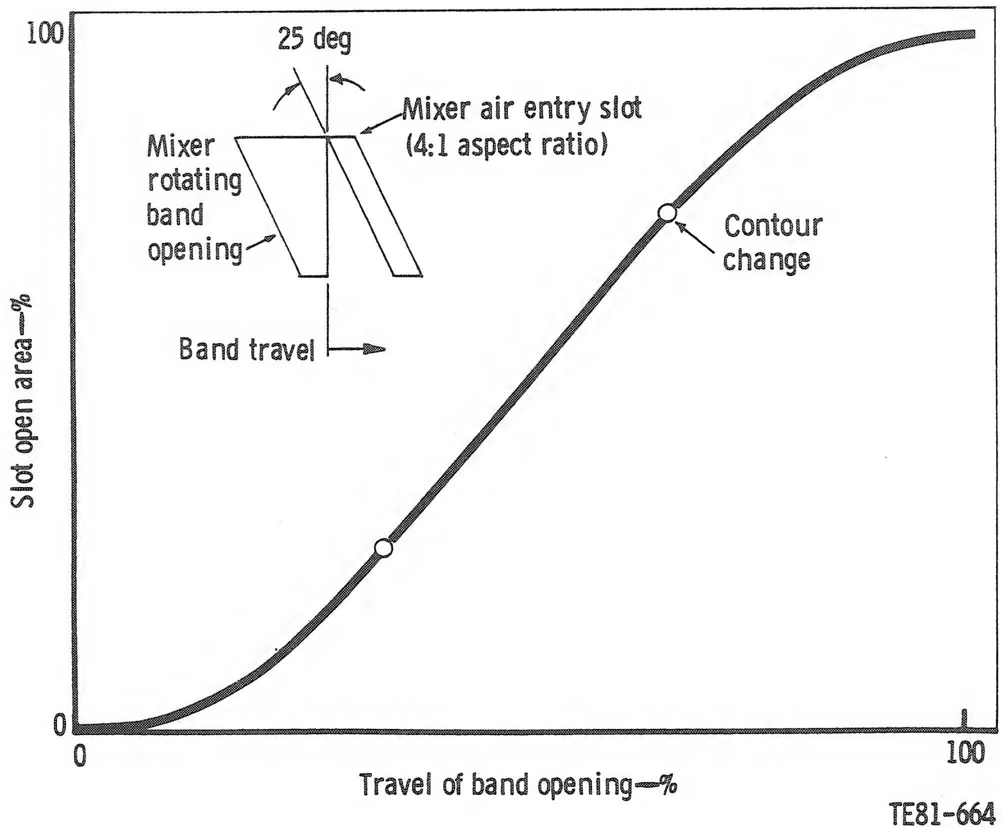

Figure 11. - Air mixer variable geometry area change on angled slot.

For any mechanical system having sliding surfaces that operate in a hot environment, allowances must be considered for differential thermal growths. To maintain a viable system, the inside surface of the mixer rotating band was spray coated with a 0.20 mm (0.010 in.) thick ceramic coating to act as a dry lubricant and antiseizing compound. Appropriate radial gaps must be allowed to account for thermal expansion of the hot inclined-slot sheet metal. Figure 12 indicates for small size slots the loss in controllable area that might result from small gaps between the band and the base metal.

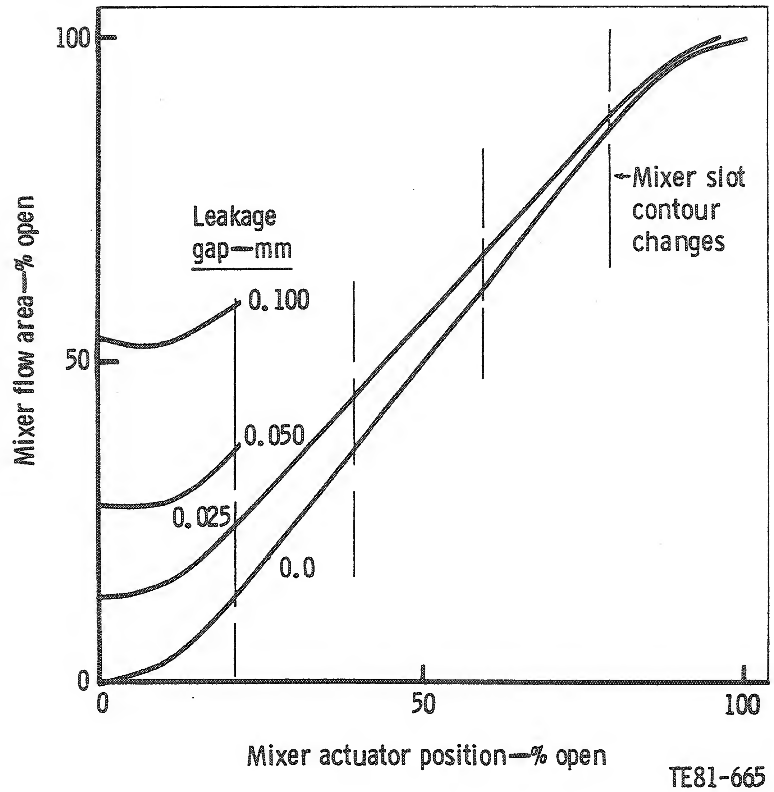

Figure 12. - Predicted mixer performance.

Early experience with the quick-quench mixer pointed out that excessive leakage was occurring under the mixer band, thus reducing the controllable range of areas. The mixer was then modified to reduce the radial gap under the rotating band. At the same time the band was stiffened with a central ring, and edge containment rings were added at the band edges to resist lifting of the band when rotated by the actuating mechanism.

Cooling of the mixer was accomplished first by a cooling air film injected over the entire internal circumference of the mixer upstream of the first row of inclined slots. The thermal barrier coating used on the inner surface of the rich zone was also extended to the mixer inner surface. Effusion cooling holes were drilled in the mixer aft flange and the turbulence of the aft rich zone cooling air assisted in cooling the mixer from the back side.

Throughout the test program measured metal temperatures at the mixer remained below 510 K (1000°F), and there were no failures in the mixer hardware or variable area system.

Lean Zone

The lean zone, immediately downstream of the mixer, as well as the final dilution zone, is of conventional design with variable-area dilution holes for pressure drop control. Cooling for these zones, since all combustion is lean, is accomplished with DDA's quasi-transpiration wall cooling material, Lamilloy®*. The use of Lamilloy minimizes the amount of cooling air required for the final zones of the combustor, leaving more air for the penetrating jets of the dilution holes and the mixer slots. A photograph of the lean dilution zone hardware is shown in Figure 13. Again a variable area mechanism was designed for the dilution holes to aid in setting desired lean zone equivalence ratio and pressure drop levels. The variable area consisted of five equally spaced, circular holes of 16.0 mm (0.6325 in.) diameter in the dilution zone body, and 23.8 mm (0.9375 in.) in the elevated rotating band. Preliminary testing dictated reducing the dilution zone hole diameters for better controllability by reducing the actuation sensitivity present with the larger size holes through the combustor body. Changes in the rotating band holes were not deemed necessary to the operation of the dilution zone.

Variable Geometry Operation

The purpose of the three variable area systems designed into the RQL combustor was to develop a combustor to meet the program goals over the entire operating range of the Allison Model 570-K engine and significantly reduce the test time required for parametrically evaluating the combustor's performance. Changes in rich zone and/or lean zone equivalence ratios could be made while maintaining system operating parameters, e.g., pressure drop or residence time. Also, changes in pressure drop could be achieved with no change to equivalence ratios or mass flow.

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*Lamilloy is a registered trademark of the General Motors Corporation.

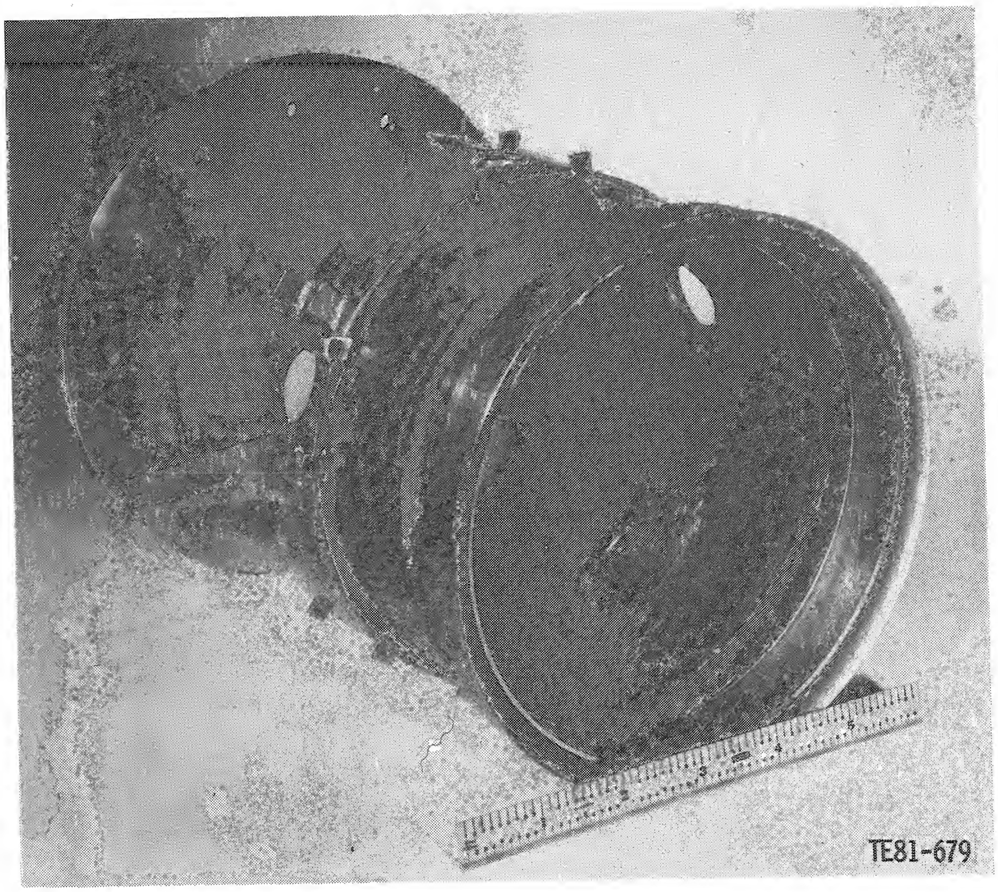

Figure 13. - Transpiration cooled RQL dilution zone.

Predicted performance of the RQL combustor operating on middle distillate (ERBS) fuel at the Model 570-K maximum continuous power condition is shown in Figures 14 through 18. Obtainable ranges in operation for the RQL combustor are as follows:

Parameter	Range
Rich zone equivalence ratio	1.2-2.5
Lean zone equivalence ratio	0.4-0.65
Pressure drop	3-7%

Variable geometry settings for each operating condition were computed from the flow maps based on cold flow testing discussed in Section IV--Experimental Systems. Calibration of the flow maps was conducted with each hot flow data set to maintain good predictability.

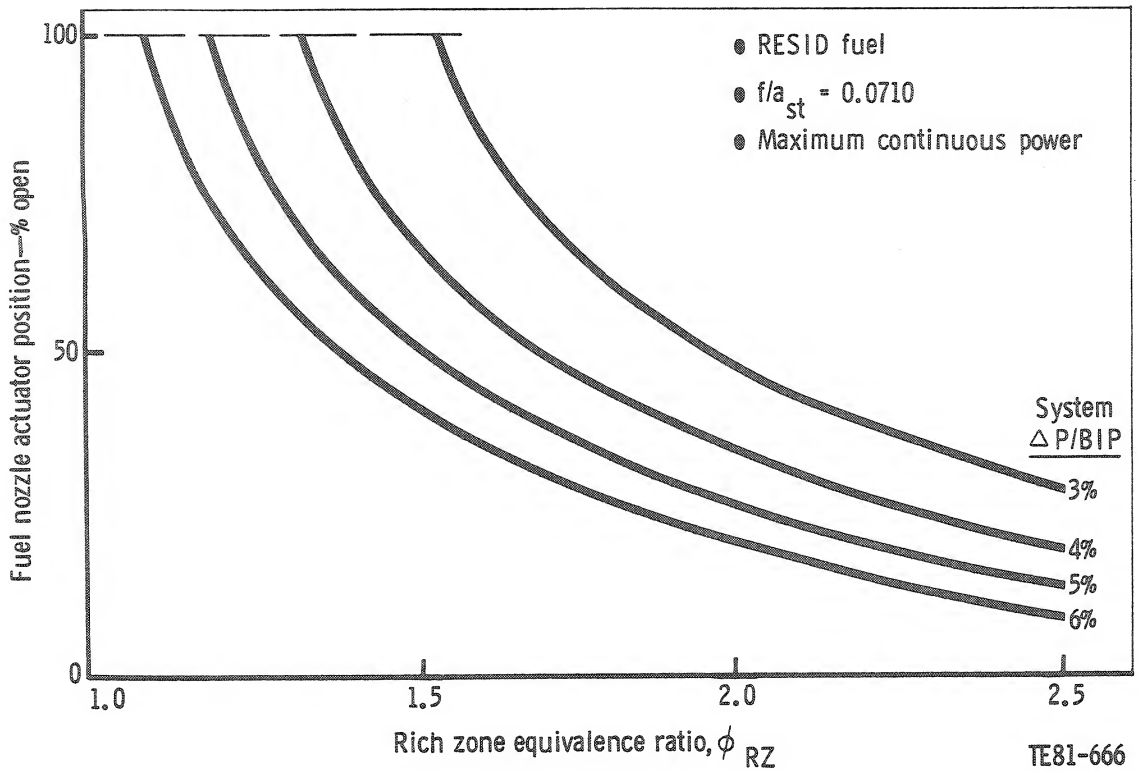

Figure 14. - Predicted fuel nozzle actuator settings for Concept I combustor performance.

Concept II--Rich/Quench/Lean with Preheat

It was anticipated that the Concept I RQL combustor might have difficulty vaporizing the heavy residual fuel. With this in mind a preheating/vaporizing section was designed so that this new section might be inserted between the fuel nozzle and the rich zone (see Figure 19). The preheat/vaporizer section consisted of a very small preburner, a hot gas distribution annulus, radial injection ports to direct the hot preheat exhaust flow, and a vaporization tube with an exit swirler to set up a swirl recirculation in the rich zone with the prevaporized fuel and air. A photograph of the preheat/vaporizer hardware is shown in Figure 20. The offset preburner and the hot gas injection ports are more clearly seen in Figure 21.

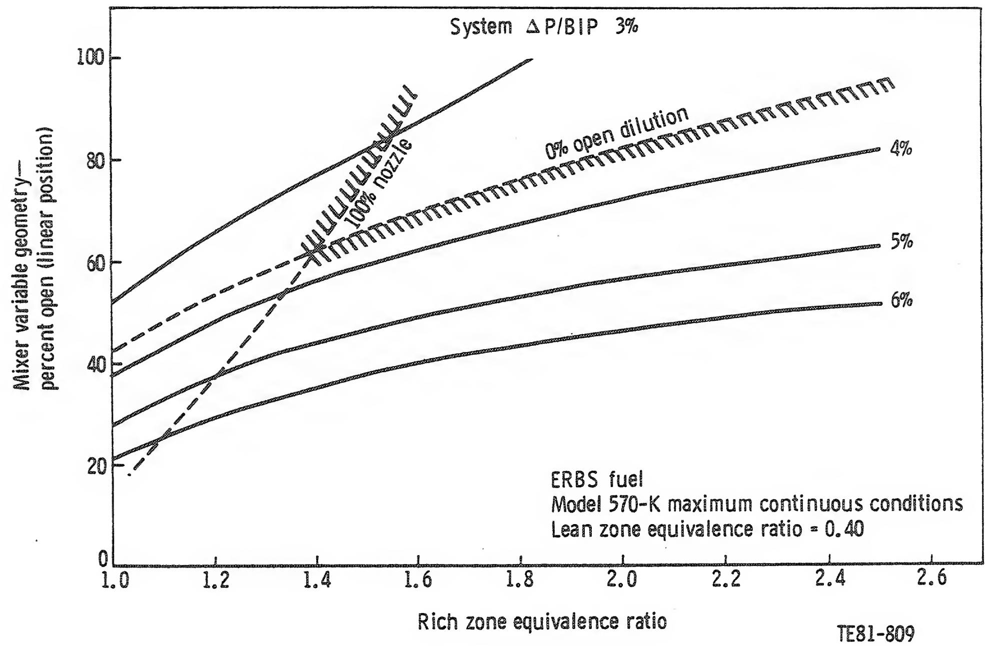

Figure 15. - Predicted mixer actuator settings for Concept I combustor performance at 0.4 lean zone equivalence ratio.

Conceptually, a small amount of fuel was to be burned in a lean combustion preburner. The preburner exhaust was designed to be 1090 K (1500°F). This gas was then to be distributed in a small plenum surrounding the face of the airblast or air assist fuel injector. Six equally spaced slots injected the hot preburner exhaust gas into the fuel nozzle spray to augment the vaporization process. The preburner was sized so that after injecting at 1090 K (1500°F) into the fuel spray, the final bulk temperature after complete vaporization of the balance of the fuel would be 810 K (1000°F). The vaporized fuel and air mixture would then enter the rich zone after passing through a flow recirculation swirler at the end of the vaporizer tube. From this point the combustion process would be the RQL process of Concept I.

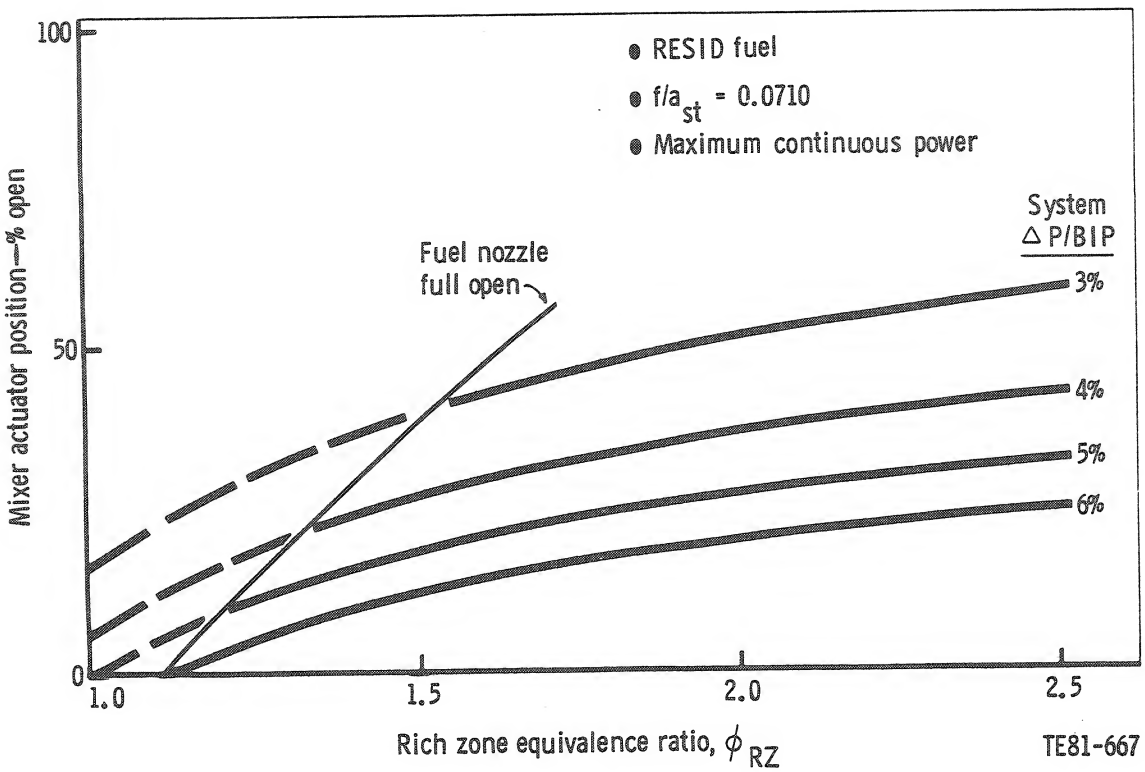

Figure 16. - Predicted mixer actuator settings for Concept I combustor performance at 0.5 lean zone equivalence ratio.

The preburner is a conventionally sized combustor using a small low flow air blast/air assist fuel nozzle. Cooling was accomplished with Lamilloy, as the preburner primary zone operates lean at an equivalence ratio of 0.8. To aid in distributing the 1090 K (1500°F) exhaust, the preburner was mounted off the main combustor centerline, as seen in Figure 21.

Since it had been assumed that the preburner system might be required because the evaporation rate of the residual is the rate-controlling process, the vaporizer section was sized to ensure vaporization of the residual fuel prior to its entering the rich zone. From LeFebvre and Ballal (Ref. 8) the average rate of fuel evaporation is:

$$m_f = 1.33\, \pi n\, (k/Cp)_g\, \ln(1 + B)(1 + .25\, Re^{0.5})$$

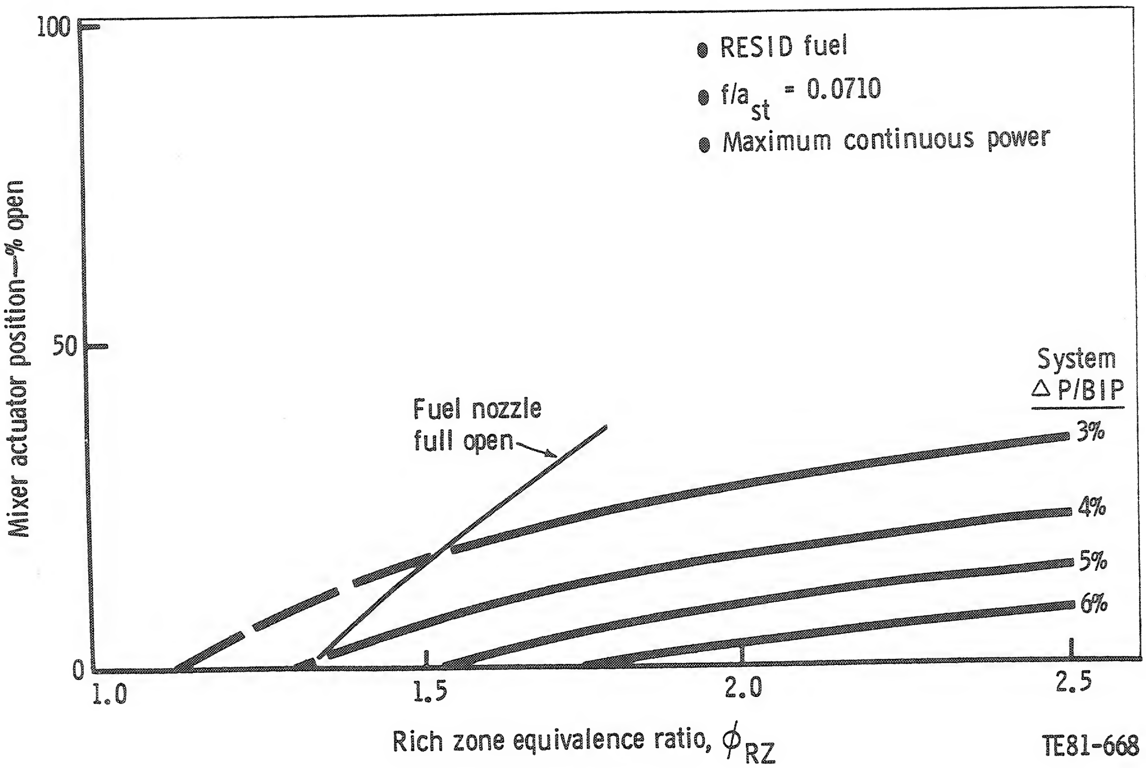

Figure 17. - Predicted mixer actuator settings for Concept I combustor performance at 0.6 lean zone equivalence ratio.

Since the evaporation rate must be equal to the flow rate:

$$m_f = n\rho_L \ (4\pi/3)(D/2)^3/t$$

Assuming that the average droplet velocity is one-half the gas velocity, and that the average drop diameter is two-thirds the initial drop diameter, equating these equations and solving for the time gives:

$$t = \frac{\rho_L \ Cp_g \ D^2}{8k_g \ \ln(1 + B) \left[1 + \left(\dfrac{m_g \ D}{12\pi\mu_g \ d^2}\right)^{0.5}\right]}$$

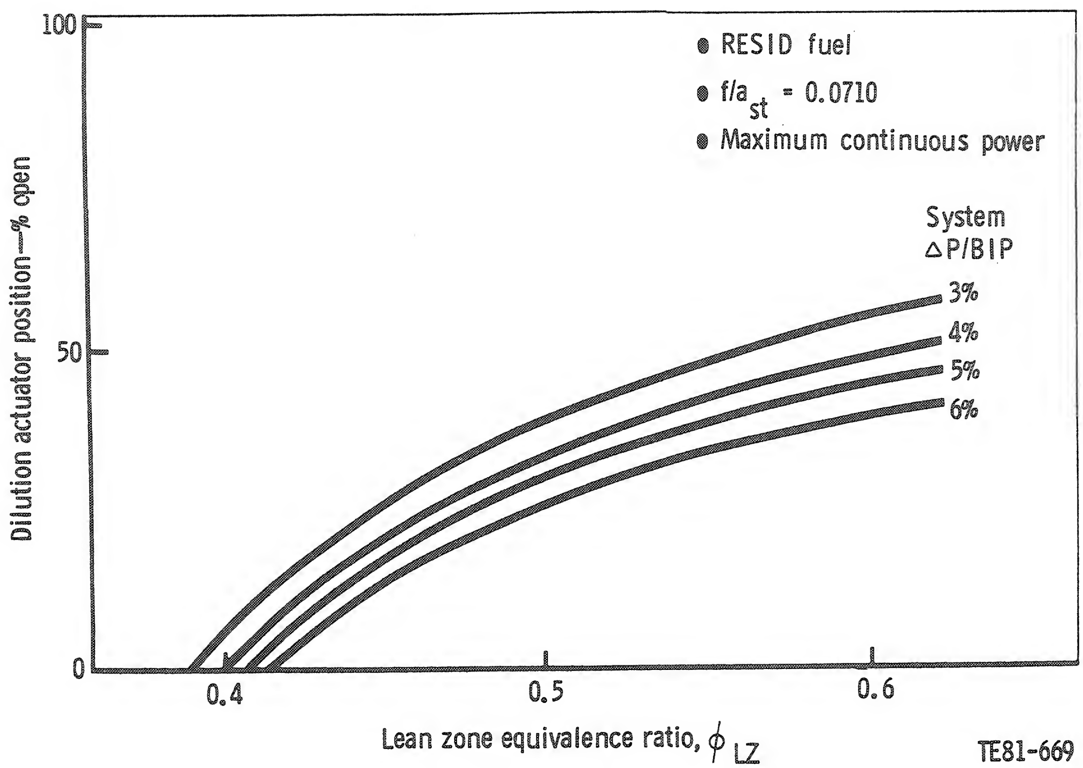

Figure 18. - Predicted dilution actuator settings for Concept I combustor performance.

This vaporization time must be less than 6.5 ms for the residual fuel, according to Spadaccini (Ref. 15), to avoid autoignition in the vaporizer at 1.03 MPa (150 psi) and 810 K (1000°F). Thus, knowing the residence time allowed and the gas velocity through the vaporizer, the volume required could be computed as functions of fuel and gas properties and fuel droplet size. Figures 22 and 23 show the vaporizor lengths required to vaporize given droplet diameters for heavy fuel oil and kerosene fuel at rich zone equivalence ratios of 2.5 and 1.2 for the Model 570-K maximum continuous power conditions.

The decision to use the same variable area air blast/air assist fuel nozzle from the Concept I RQL combustor determined the diameter of the vaporizer tube at 76 mm (3.0 in.). Early testing with the Concept I combustor demonstrated very high smoke and prohibitive carbon deposit build-up in the rich zone for equivalence ratios above 2.0. Thus a maximum rich zone equivalence ratio of 1.8 was selected as the vaporizer design value for the residual fuel. These

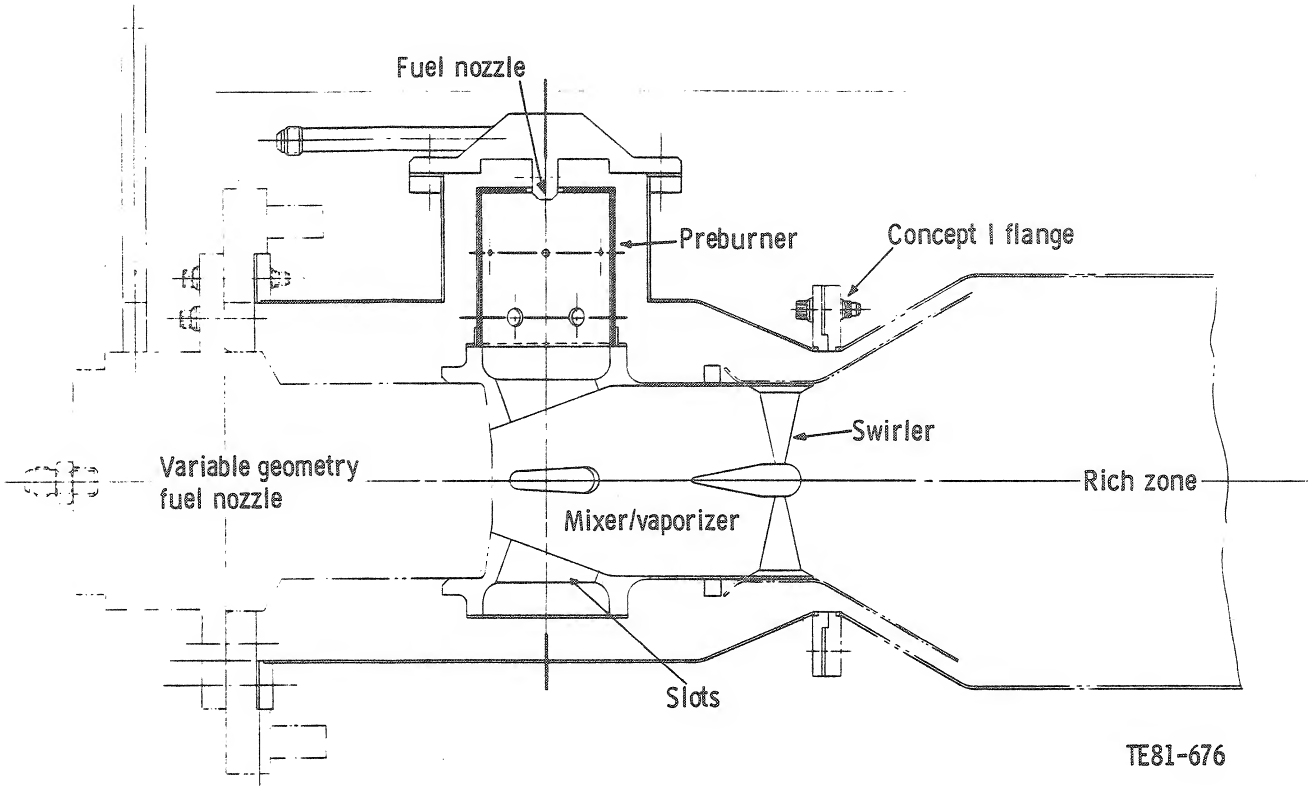

Figure 19. - Concept II fuel preparation chamber design--side view.

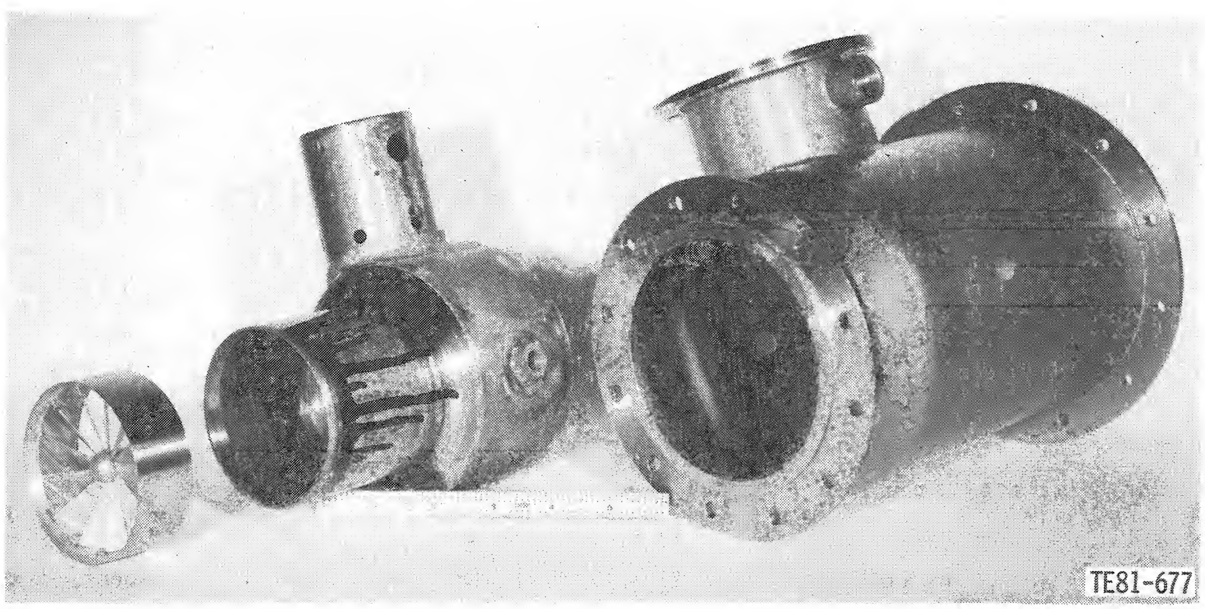

Figure 20. - Concept II preheat/vaporizer hardware.

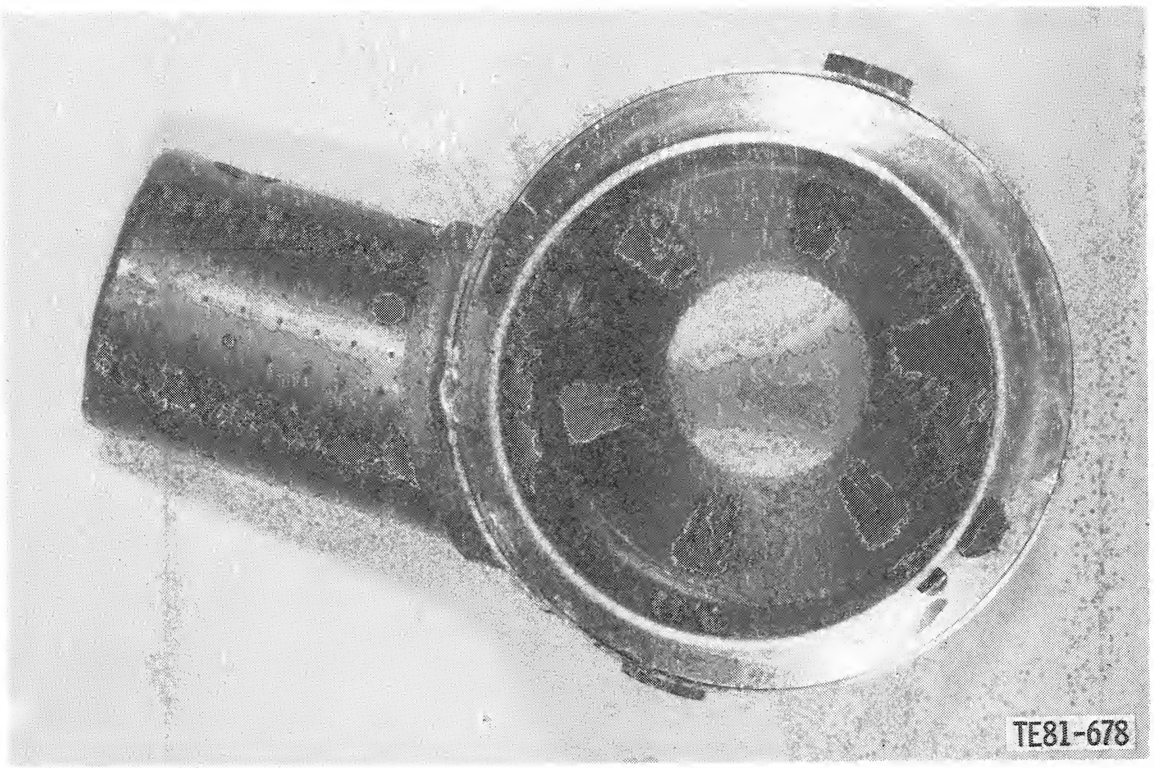

Figure 21. - Concept II offset preburner with hot gas injection ports.

design conditions of 76 mm (3.0 in.) diameter, 1.8 rich zone equivalence ratio, and residual (heavy fuel oil) resulted in a constant cylindrical length of 95 mm (3.75 in.) for a vaporizer volume of 431 cm^3 (26.5 $in.^3$).

The preburner, mixer, and vaporizer hardware for Concept II were fabricated; but, because of the success attained on Concept I with the residual fuel, the Concept II hardware was not rig tested.

Concept III-- Lean/Lean

For some industrial and utility applications, the fuels used may be quite low in FBN and thus not require that RQL combustors be used in the engine. For these low FBN applications a much more conventional lean/lean combustor can be used. A lean/lean combustor operates with a lean primary zone to reduce the reaction temperature and thus the thermal NO_x emissions produced. Final

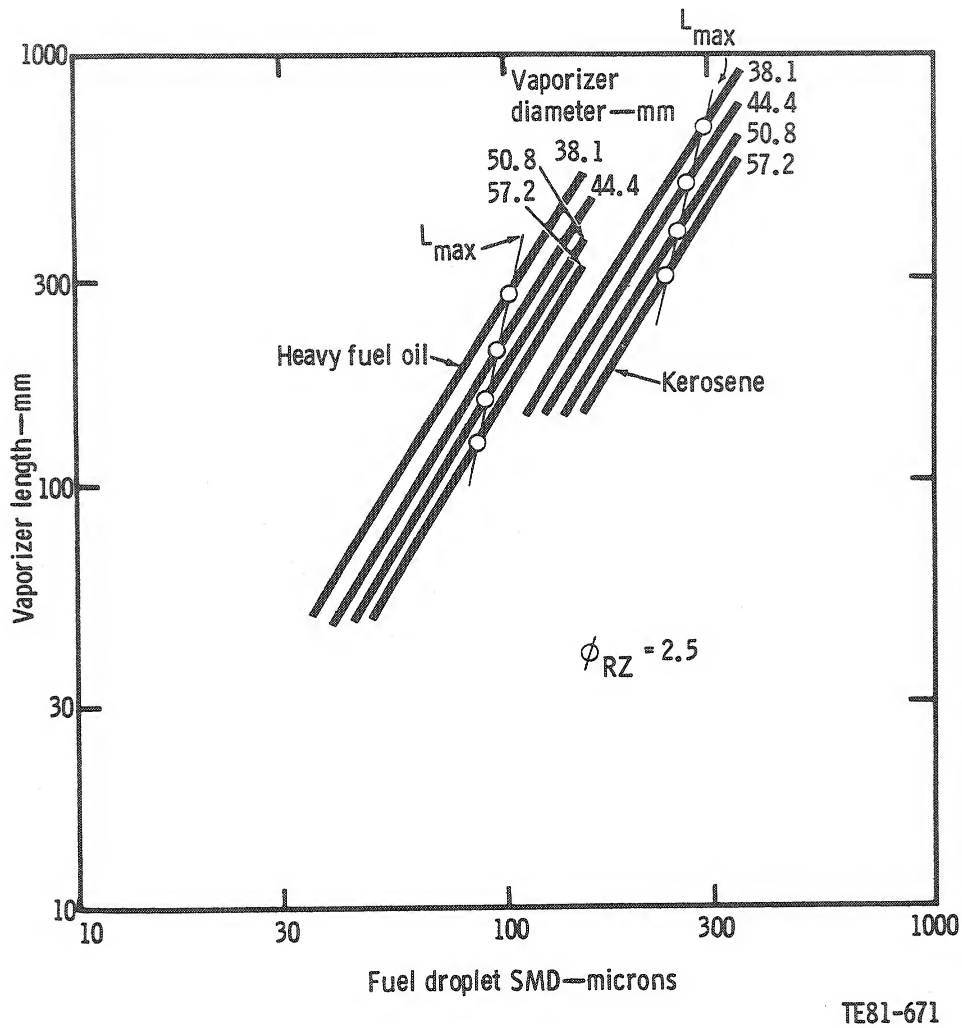

Figure 22. - Vaporizer length requirements for combustor Concept II at 2.5 rich zone equivalence ratio.

oxidation and exhaust temperature pattern adjustment is then accomplished in a lean dilution zone. Since these combustors operate at lower reaction temperatures, the volume required for oxidation of the fuels is larger than conventional, rich primary zone combustors.

A long conventional combustor was utilized for this concept. The combustor was modified to accept the Concept I--RQL combustor fuel nozzle, so that variation in the primary zone stoichiometry could be evaluated. Hole sizes were changed to produce a combustor having a pressure drop of 6% and primary zone

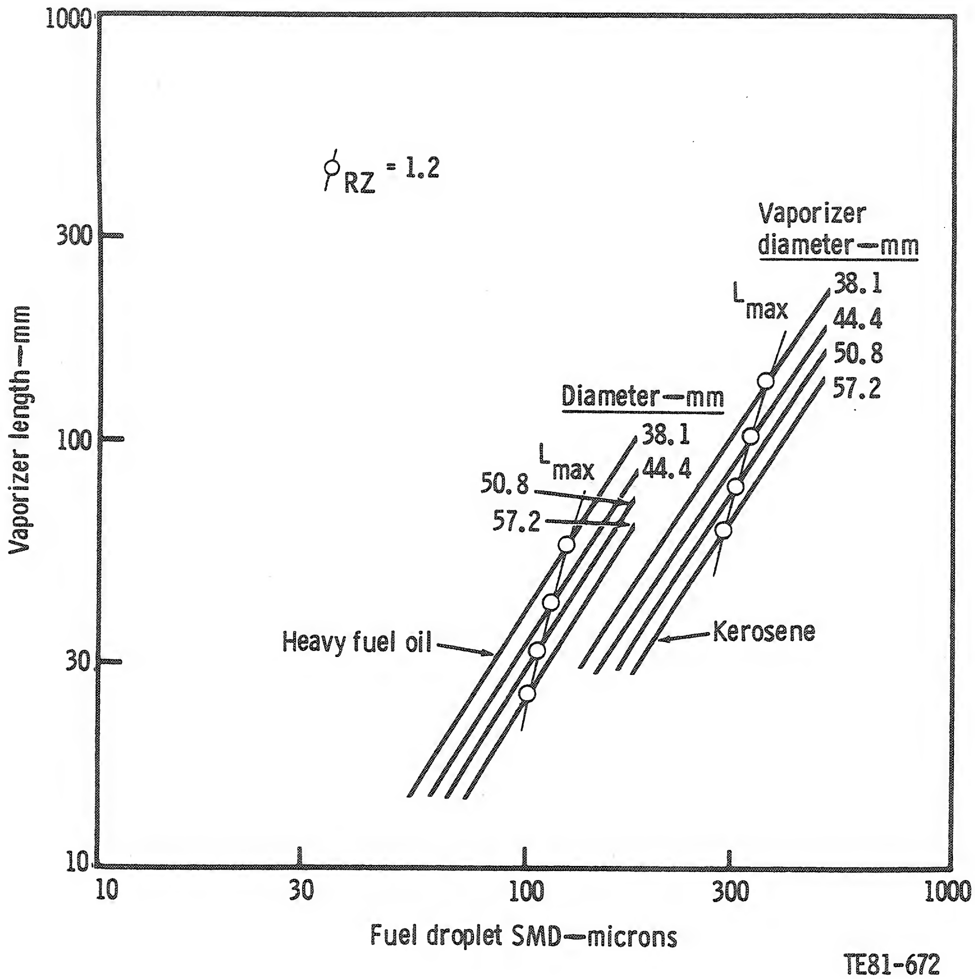

Figure 23. - Vaporizer length requirements for combustor Concept II at 1.2 rich zone equivalence ratio.

equivalence ratios which varied from 0.60 to 0.71 over the range of variable area in the fuel nozzle. A cross-sectional sketch of the lean/lean combustor is presented in Figure 24 and a photograph in Figure 25. This combustor minimizes the quenching of CO and UHC in the wall cooling by using a reverse-flow baffle in the primary zone to flow cooling air upstream around the toroidal dome and then into the fuel spray from the fuel nozzle. Thus, any unoxidized components quenched by the cooling air again must pass through the primary zone. Also, the plug flow zone is cooled by a cylinder of Lamilloy, which has been shown to quench very few of the reactants when compared to traditional film cooling. This lean/lean combustor was tested in the combustor rig and its performance discussed in Section V--Test Results.

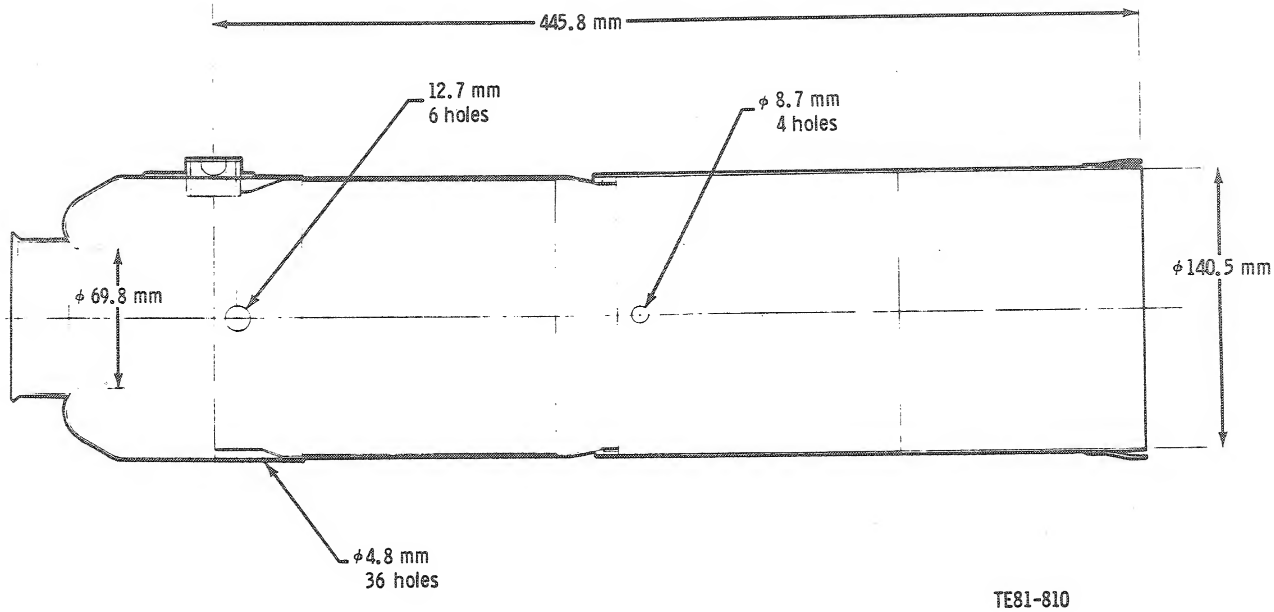

Figure 24. - Concept III lean/lean combustor--sketch.

Figure 25. - Concept III lean/lean combustor--photograph.

III. FUELS AND FUEL SYSTEM

TEST FUELS

Three base-line fuels were supplied to DDA for this combustor development program:

- o ERBS petroleum middle distillate (Fuel A) (Ref. 16)
- o RESID petroleum residual (Fuel B)
- o SRC-II coal derived middle distillate (Fuel C)

The ERBS (Experimental Referee Broadened-Specification) distillate, a special blend of kerosene and hydrotreated catalytic gas oil, is a hypothetical representation of a future distillate fuel. It is similar to DF-2 fuel, which is currently used in industrial gas turbine engines.

The RESID is a minimally treated, high viscosity petroleum residual, essentially a No. 6 heating oil.

The SRC-II is a solvent refined coal-derived liquid fuel sufficiently treated to approach industrial fuel combustion quality. However, the SRC-II fuel does present serious handling and toxicity problems not associated with current industrial liquid fuels.

Viscosity-temperature characteristics of the three test fuels are compared to current aviation and industrial fuels in Figure 26. Table III presents key test fuel properties and thus illustrates the following major differences that these fuels have from current DF-2 fuel:

- o Lower hydrogen content
- o Higher ash content
- o Extended boiling range
- o Increased viscosity
- o High levels of FBN

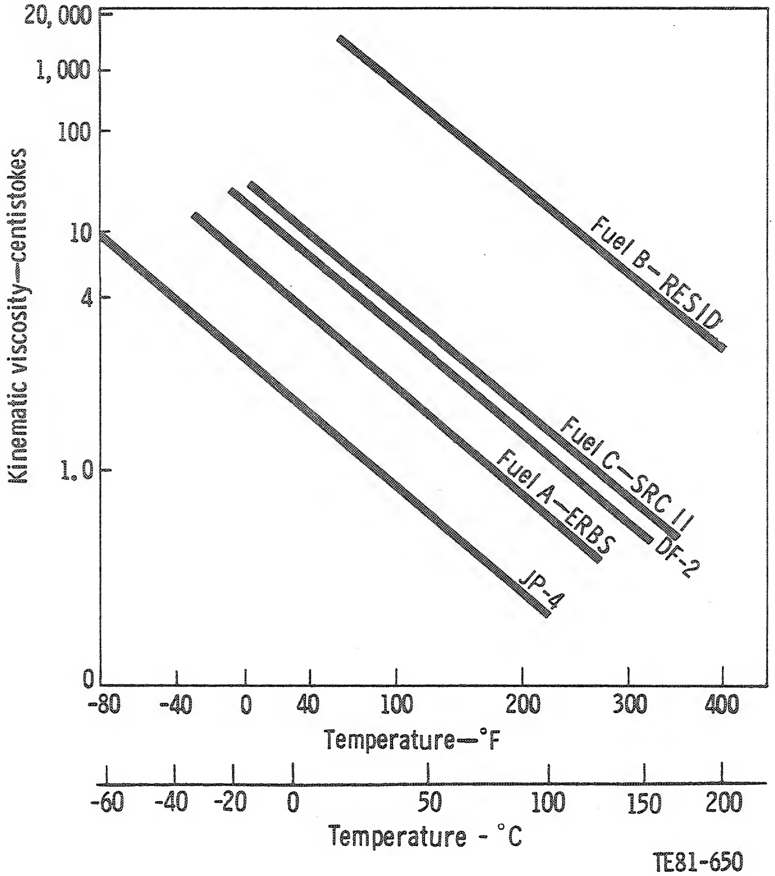

Figure 26. - Viscosity-temperature relation for test fuels.

The three test fuels were thoroughly characterized to define fuel property data for performance analysis. A comprehensive tabulation of fuel property data appears in Table IV.

Table III.
Key fuel properties.

Property	DF-2	Fuel A ERBS	Fuel B RESID	Fuel C SRC-II
Hydrogen, wt %	13.1	12.88	11.24	8.81
Nitrogen, wt %	----	0.013	0.27	0.88
Ash, wt %	----	.001	.028	.001
10% distillation, K (°F)	460 (368)	464 (375)	573 (572)	483 (410)
End point, K (°F)	679 (762)	614 (645)	>825 (>1026)	587 (597)
Pour point, K (°F)	247 (-15)	236 (-35)	278 (+40)	228 (-50)

Table IV.
Comprehensive fuel properties.

Property	Fuel A ERBS	Fuel B RESIDUAL	Fuel C SRC-II
Hydrogen, wt %	12.88	11.24	8.81
Carbon, wt %	87.05	87.39	85.84
Nitrogen, wt %	0.013	0.27	0.88
Sulfur, wt %	0.09	0.56	0.28
Ash, wt %	0.002	0.028	0.001
H/C wt ratio	0.148	0.129	0.103
H/C molar ratio	1.763	1.533	1.223
Pour point, K (°F)	236 (-35)	278 (+40)	228 (-50)
Flash point, K (°F)	332 (138)	441 (335)	352 (174)
API gravity, °F 60/60	37.4	16.7	12.3
Density, kg/m^3 (lb/gal)	838.7 (6.99)	954.8 (7.97)	984.0 (8.21)
Smoke point, mm	10.7	---	4.8
Viscosity @ 300 K (100°F), cs	1.69	640	3.84
Cetane No.	38	---	---
LHV, MJ/kg (Btu/lb) (Ref. 20) (calculated)	42.63 (18,327)	41.71 (17,933)	40.35 (17,349)
Distillation (ASTM D-86)--K (°F)			
IBP	448 (346)	509 (457)	379 (222)
5%	461 (370)	--- (---)	475 (395)
10%	464 (375)	573 (572)	483 (410)
20%	468 (382)	625 (666)	492 (426)
30%	474 (394)	664 (736)	500 (440)
40%	481 (406)	--- (---)	508 (455)
50%	488 (418)	729 (852)	516 (469)
60%	496 (433)	--- (---)	525 (485)
70%	508 (454)	786 (955)	534 (502)
80%	527 (489)	>825 (>1,026)	546 (524)
90%	565 (558)	>825 (>1,026)	562 (552)
95%	593 (608)	>825 (>1,026)	578 (580)
EP	614 (645)	>825 (>1,026)	587 (597)

Although the RESID and SCR-II initially contained relatively high levels of FBN, all three fuels were also blended with pyridine, a toxic liquid hydrocarbon high in bound nitrogen content. The pyridine was systematically added to the test fuels to evaluate the contribution of FBN to NO_x formation and to determine the amount of FBN which could be tolerated under existing emissions regulations. Table V lists the key properties of pyridine and the parametric pyridine/fuel blends tested at the maximum continuous power condition. The pyridine blending apparatus is described below in the subsection entitled Fuel System.

Table V.

Pyridine key properties and blends.

Key Properties

Property	2-Vinyl pyridine (C_7H_7N)
Hydrogen, wt % (theoretical)	6.71
Carbon, wt % (theoretical)	79.97
Nitrogen, wt % (theoretical)	13.32
H/C wt ratio	0.084
H/C molar ratio	1.000
API Gravity, °F 60/60	10.1
Density, kg/m^3 (lb/gal)	999.0 (8.32)
Boiling Point, K (°F)	Decomposes at 431 (316)
LHV, MJ/kg (Btu/lb) (calculated)	33.62 (14,453)

Pyridine/Fuel Blends Tested

Max Continuous Power Operation

Nominal Fuel Flow = 135 kg/hr (297 lb/hr)

Nominal pyridine flow-- cm^3/s (gal/hr)	Nominal FBN content of pyridine/fuel blend--wt %		
	Fuel A ERBS	Fuel B RESID	Fuel C SRC-II
0.0 (0.0)	0.013	0.27	0.88
1.1 (1.0)	0.369	0.612	1.195
1.6 (1.5)	0.545	0.781	1.352
2.1 (2.0)	0.721	0.950	1.508

The fuel analysis data found in Tables IV and V are a composite of analyses provided by DDA personnel, Gulf Mineral Research Corporation, and Pittsburg and Midway Coal Mining Company. These analyses were performed on pretest fuel samples.

Post-test fuel samples were sent to Gulf Mineral Research Corporation for verification analysis. Laboratory results revealed no reportable changes in the properties of any of the fuel samples analysed--A, B, C, and C_7H_7N.

FUEL SYSTEM

A fuel storage and delivery system was designed for fuel-flexible, efficient operation when using the three test fuels and pyridine. The fuel system is illustrated in Figure 27, and contains the following key features to assure successful accomplishment of the test program:

- o Three 1.04 m^3 (275 gal) fuel storage tanks, one for each fuel
- o In-line heater to ensure proper delivery and operation with RESIDUAL fuel
- o High-pressure, low-flow metering pump for addition of pyridine to the fuels
- o Mixing section to ensure homogeneous fuel/pyridine distribution

Fuel barrels were stored in a fuel farm storage facility. When required for test the fuel was placed in the proper 1040 litre (275 gal) tank in the test cell fuel pit, Figure 28. RESID fuel required special handling due to its high pour point and viscosity characteristics. An in-tank immersion heater, a tank insulation blanket, and electrically heated fuel delivery lines were required to keep the fuel temperature at 367 K (200^oF) and thus ensure proper pump operation. An in-line steam heater (shown in Figure 29) was used to further increase fuel temperature to 394 K (250^oF) at the fuel nozzle inlet in order to achieve a viscosity of approximately 10 cs, thereby enhancing fuel atomization and vaporization quality.

Pyridine was introduced into the fuel flow downstream of the fuel recirculation path to eliminate pyridine contamination and boil-off potential. The pyridine was stored in the test cell (Figure 30) and introduced into the fuel

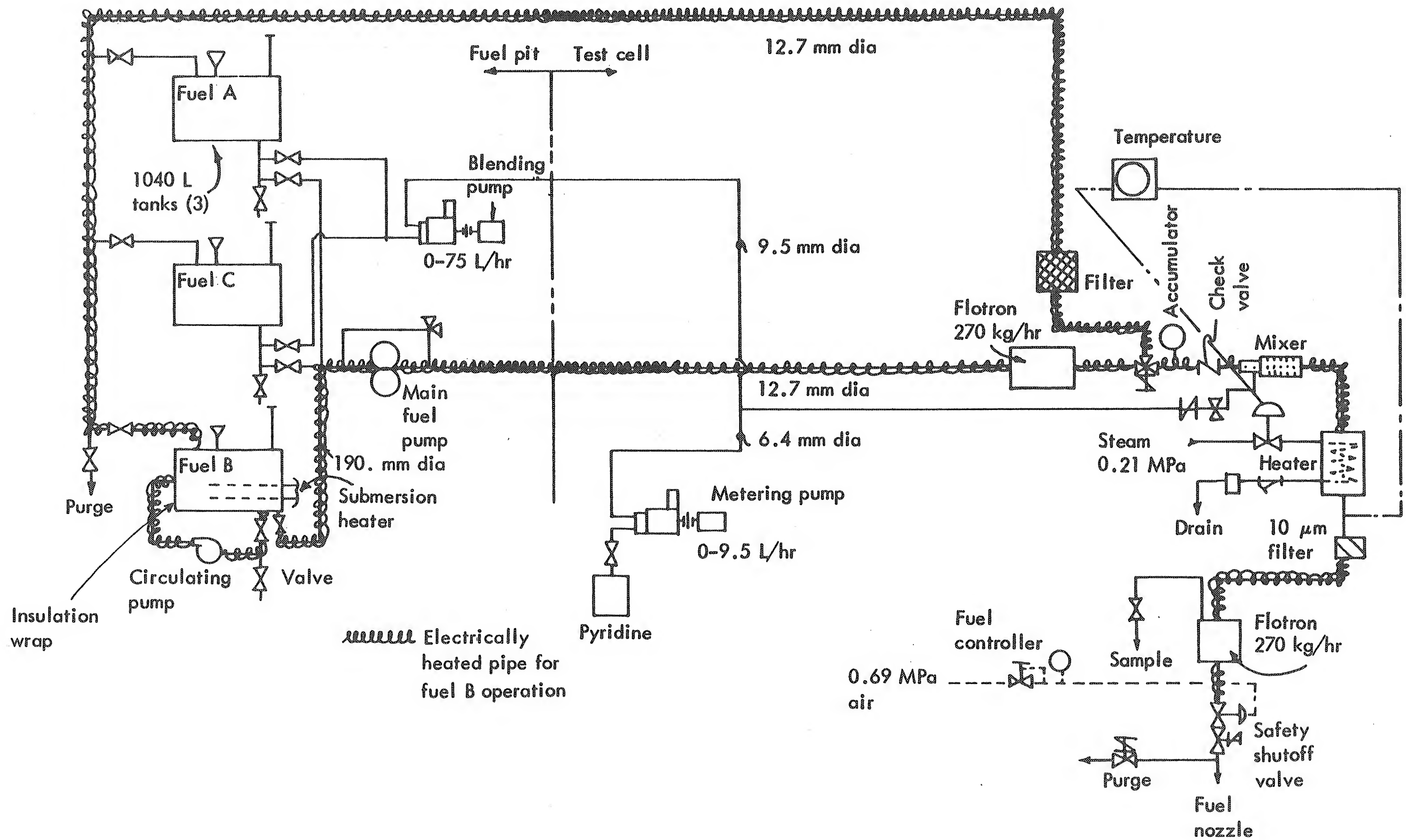

Figure 27. - Test fuel system.

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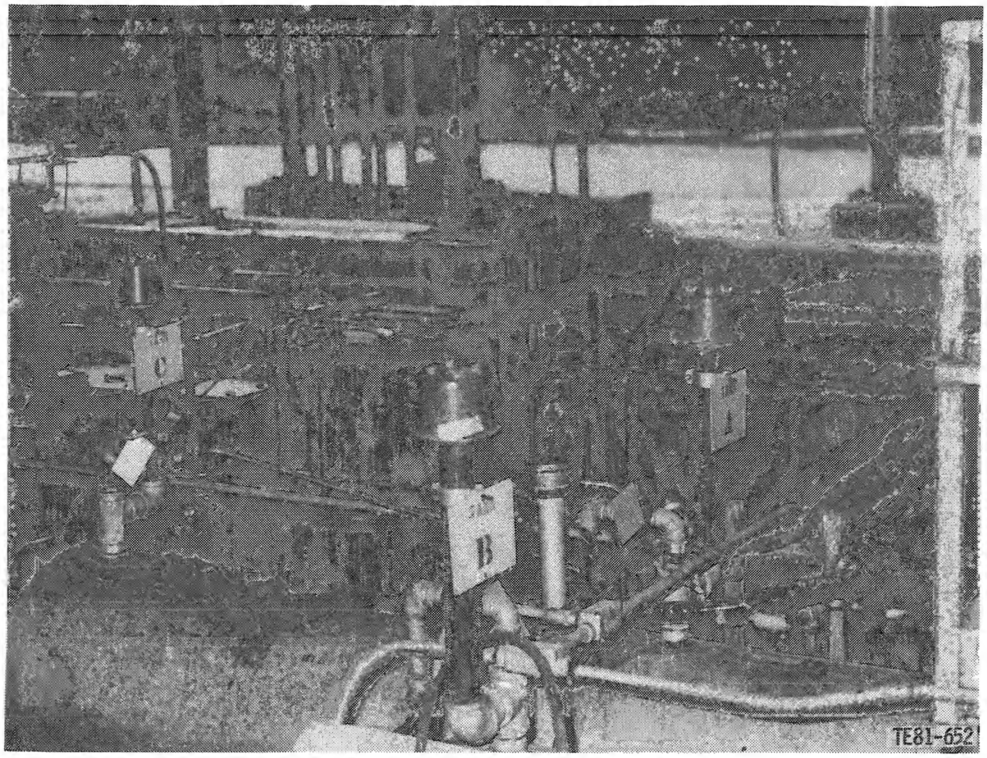

Figure 28. - Fuel pit.

flow through a high-pressure, low-flow metering pump and mixer section (Figure 31). As pyridine is a toxic and irritating substance that severely hampers fuel handling procedures, calibration of the metering pump system was carried out with water as the substitute. The calibration curve for the metering pump is shown in Figure 32. During testing, pyridine injection into the fuel was accompanied by a compensating reduction in fuel flow to accomplish a constant caloric input to the combustor. This step was taken so that a constant burner outlet temperature level was always achieved.

A series of check and hand valves provided protection from fuel-to-fuel and pyridine-to-fuel contamination. In addition, a fuel line purge procedure flushed fuel lines with the next test fuel prior to firing, and thus minimized contamination from fuel remaining in the delivery lines. Periodic fuel analyses performed throughout the test sequence revealed no fuel contamination.

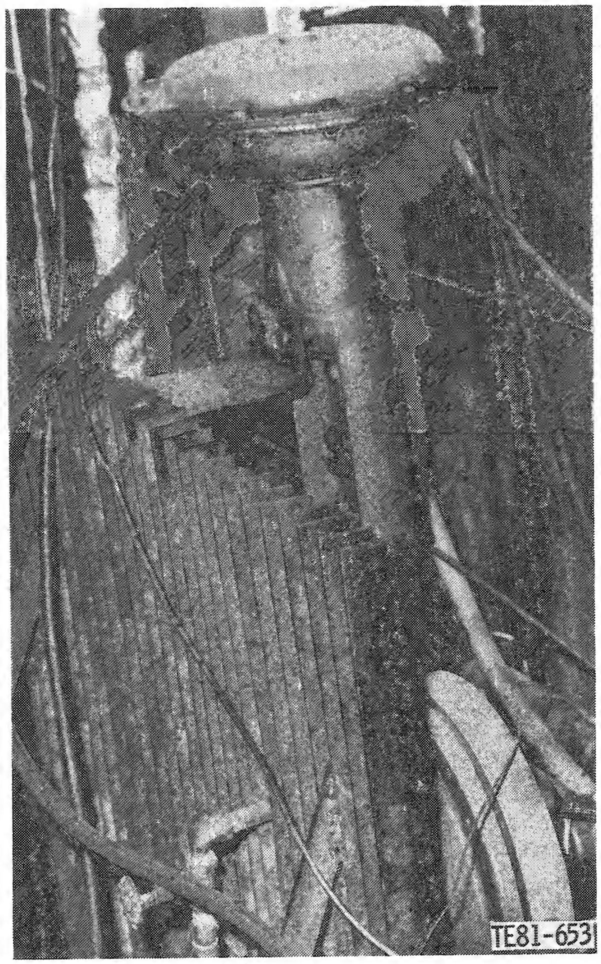

Figure 29. - Steam heater for RESID fuel (Fuel B).

Initial operation on SRC-II brought to light a problem that resulted in a continuous reduction in fuel flow rate with run time. Testing was terminated when the maximum fuel system delivery pressure was attained trying to deliver rated fuel flow. Investigation revealed the fuel system 10 micron paper fuel filters were clogged by a heavy residue (analyzed by Gulf Research Labs as high in ash content). The problem was alleviated by replacing the paper filter elements with metal aircraft-type filters and relocating them in the recirculating system to facilitate "clean-up" prior to testing.

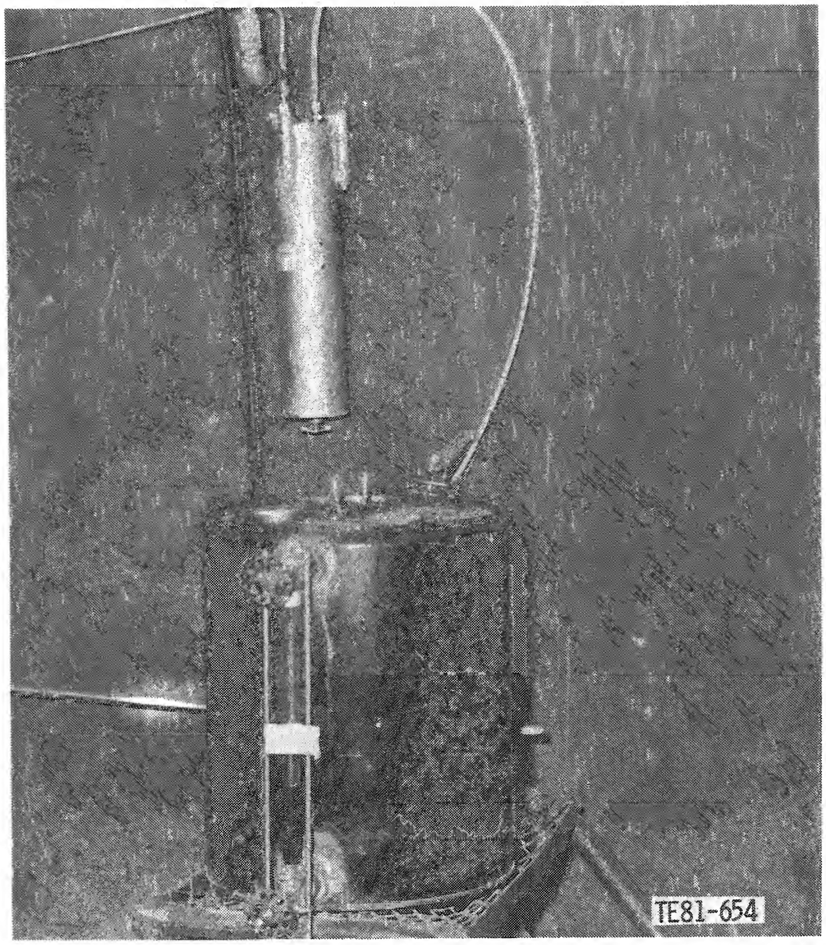

Figure 30. - Pyridine storage drum.

The toxic and irritating nature of the pyridine and the SRC-II required special handling procedures to ensure employee safety. Rubber suits, rubber gloves, respirators, and appropriate eye protection were utilized whenever personnel were exposed to the toxic liquids, as when fuel analysis samples were drawn from the rig fuel system.

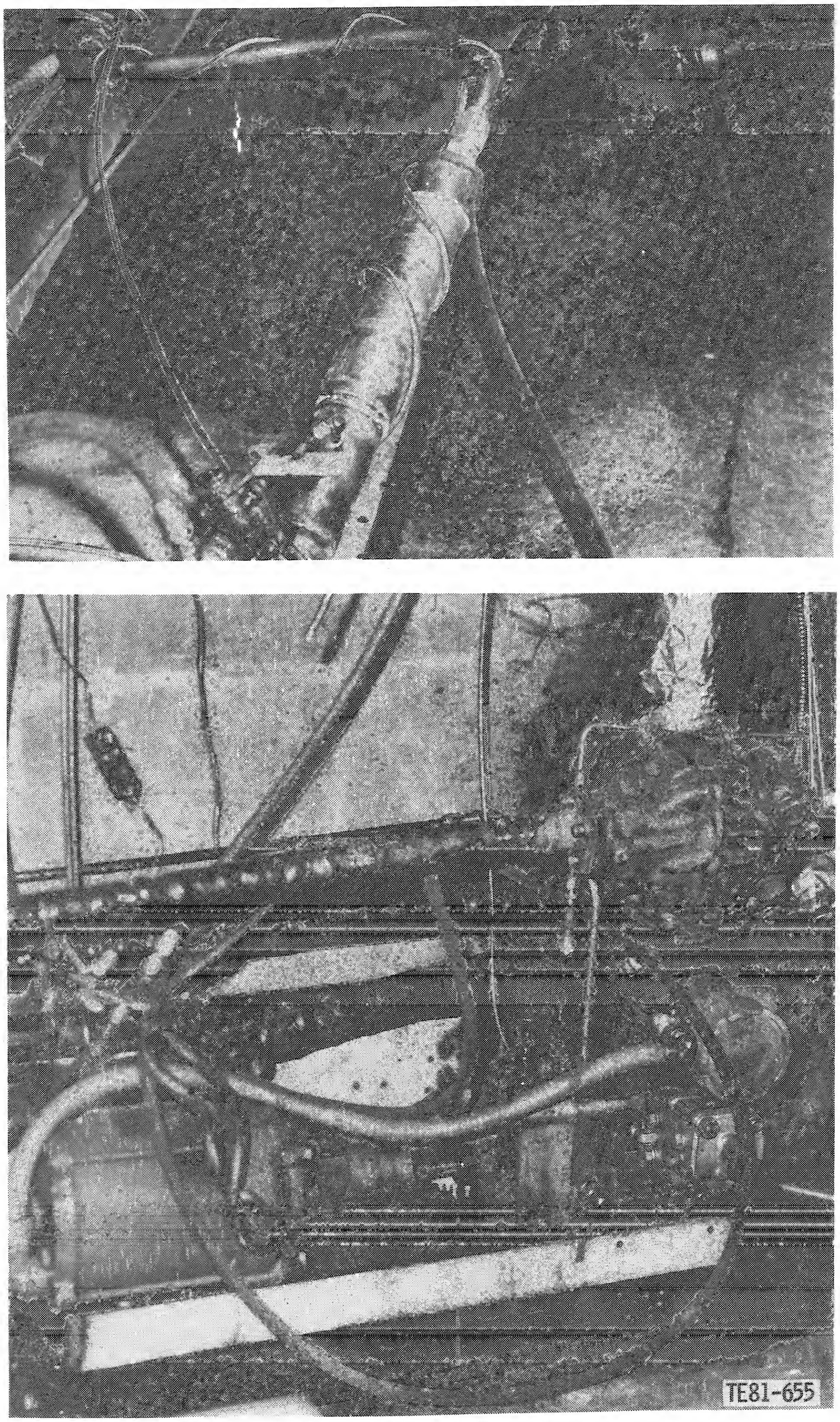

Figure 31. - Pyridine metering pump and mixer.

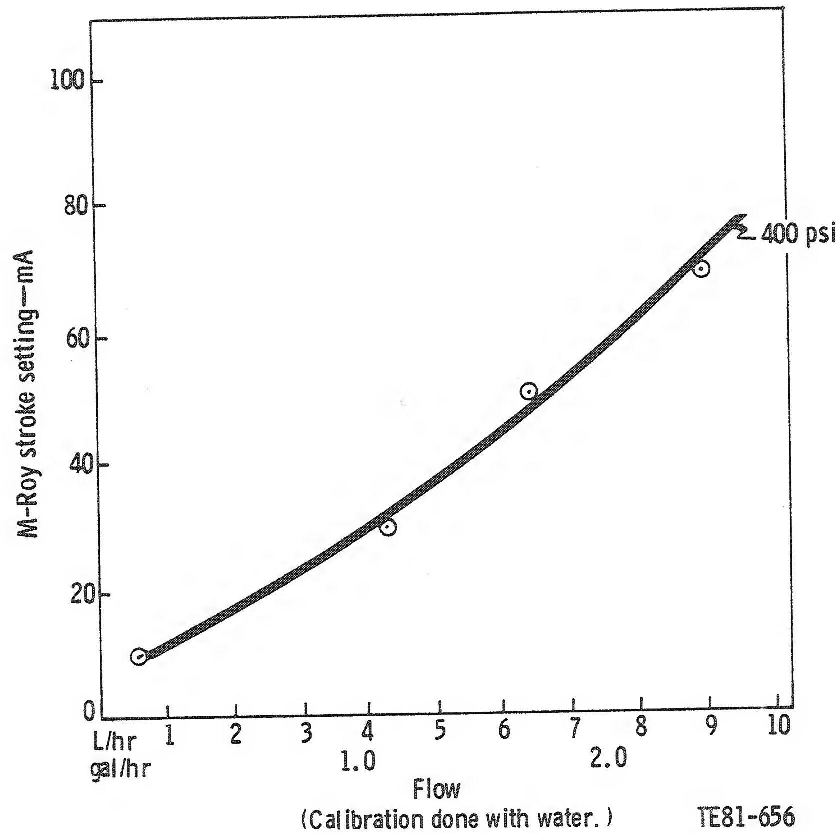

Figure 32. - Pyridine metering pump calibration test results.

IV. EXPERIMENTAL SYSTEMS

RIG TEST FACILITY

The Low NO_x Heavy Fuel Combustor Concept Program was conducted at the Research and Engineering Center (Plant 8) of DDA, located at 2001 S. Tibbs Avenue, Indianapolis, Indiana. Rig testing was accomplished in Test Cell 822 (Figure 33) one of four test cells capable of Model 570-K engine testing at conditions illustrated in Table VI.

Table VI.
Model 570-K combustor operating conditions.

Engine mode	Airflow kg/s (lb/sec)	Inlet temp K (°F)	Inlet pressure kPa (psia)	Outlet temp K (°F)	Fuel flow (DF-2) kg/h (lb/hr)
Starting	0.095 (0.210)	294 (70)	112 (16.2)	733 (859)	19.3 (42.5)
Idle	0.733 (1.614)	445 (342)	359 (52.0)	898 (1158)	18.5 (40.8)
50% load	1.313 (2.893)	559 (547)	801 (116.2)	1150 (1610)	74.5 (164.2)
70% load	1.461 (3.219)	584 (592)	934 (135.4)	1256 (1802)	96.3 (212.2)
Max continuous (nominal base load)	1.680 (3.701)	623 (661)	1142 (165.6)	1416 (2090)	134.7 (296.9)
Max rated (peak load)	1.756 (3.867)	638 (688)	1220 (177.1)	1478 (2200)	150.3 (331.4)

The company-owned combustion facility has the following major systems, as shown in the Figure 34 block diagram:

- o Airflow system
- o Fuel system (see Subsection entitled Fuel System in Section III)
- o Ignition system
- o Data acquisition and computation system

These systems are briefly discussed in the following paragraphs.

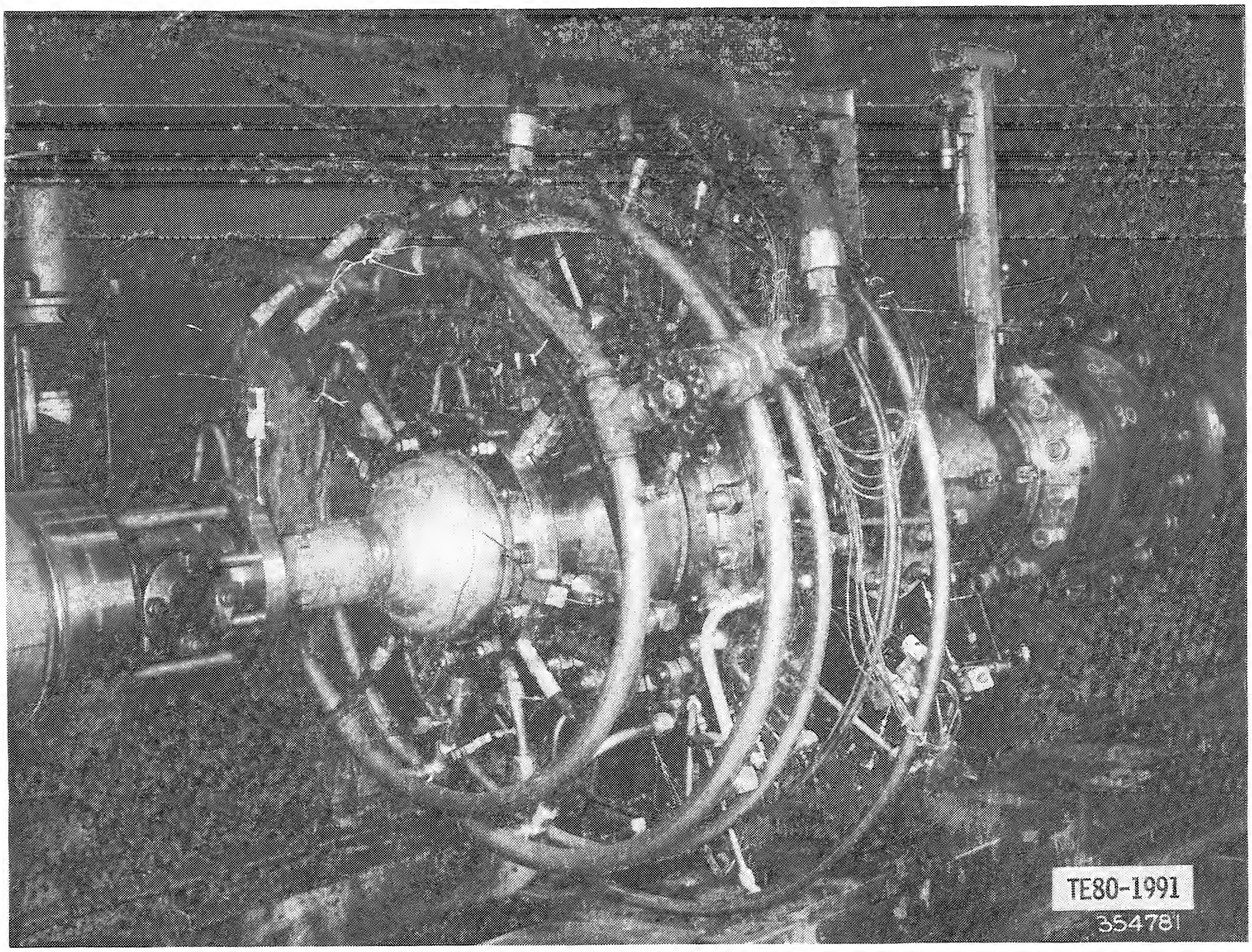

Figure 33. - Plenum-type test rig.

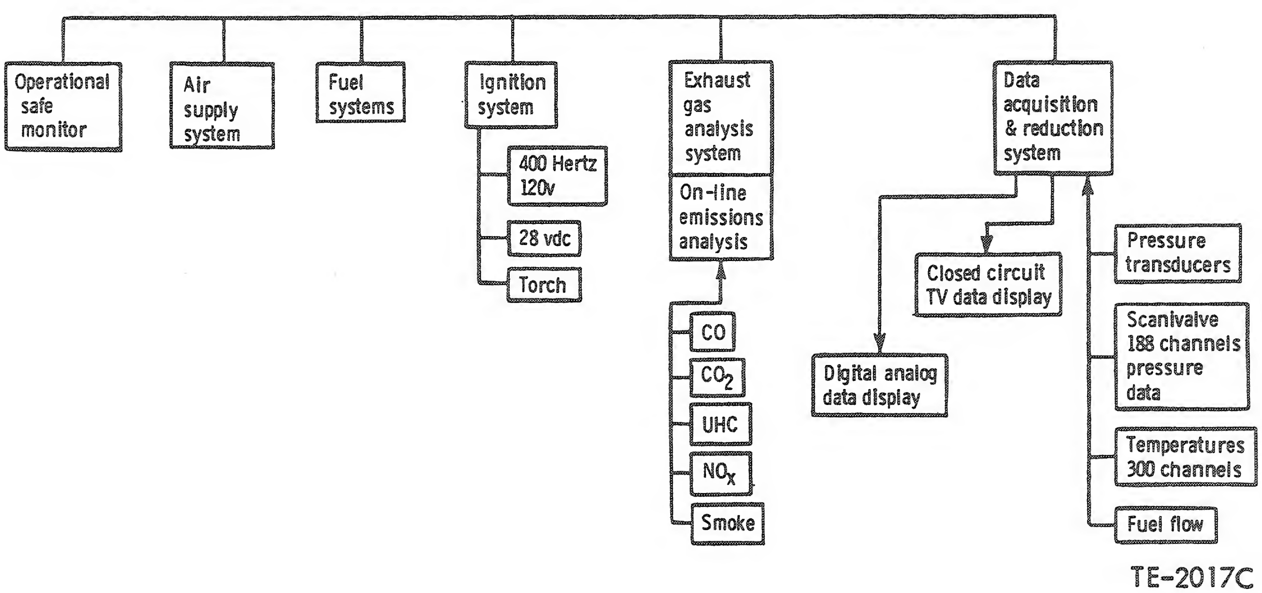

Figure 34. - Combustion test facility block diagram.

Airflow System

Figure 35 is a schematic of the air supply system including air heaters, airflow control, and pressure and temperature control. Nonvitiated high pressure air is supplied to the test section by facility compressors through indirect oil-fired heaters, which are used to elevate inlet temperatures to simulate engine compressor discharge characteristics. The exhaust piping is equipped with a water spray bar system for reducing exhaust temperatures of up to 2250 K (3600°F) without detriment to the exhaust system.

Ignition System

A portable methane-oxygen torch igniter, initiated by an air gap spark source, was employed for all testing in this program.

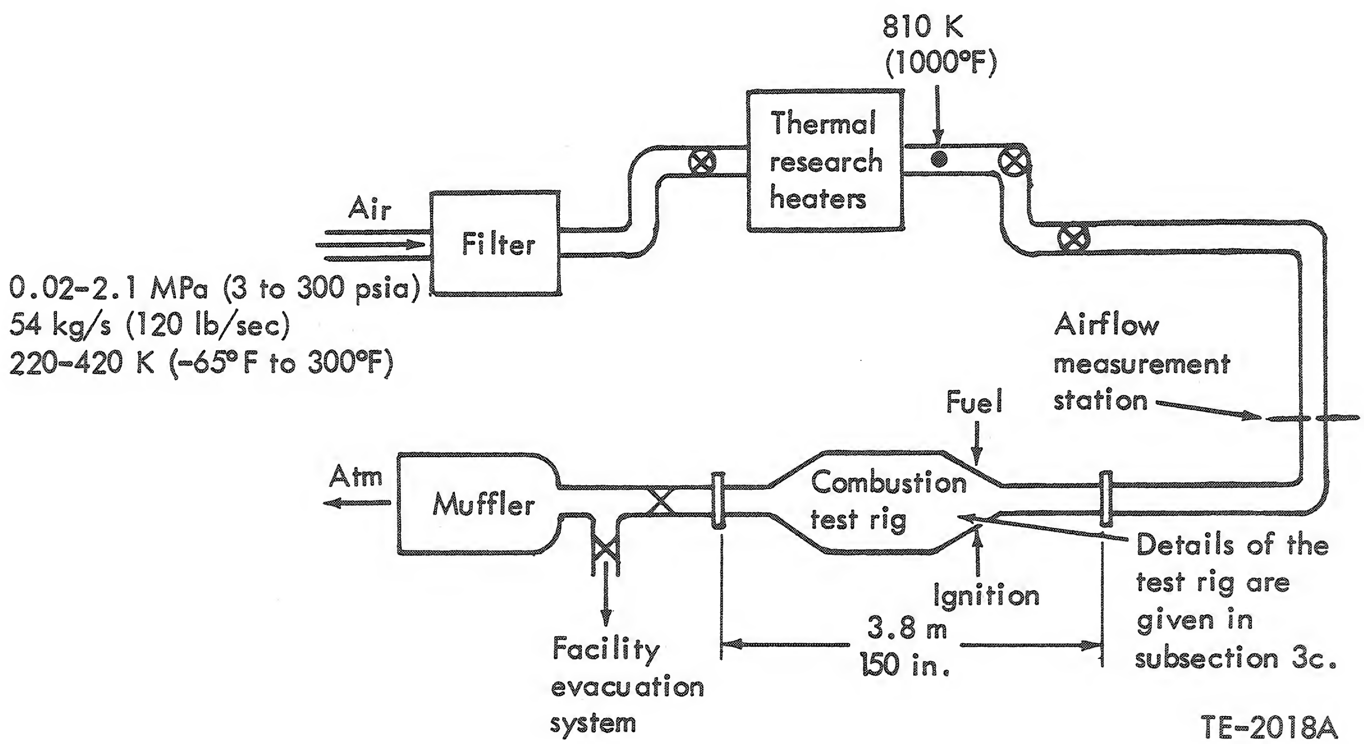

Figure 35. - Combustion test facility schematic.

Data Acquisition and Computation System

Development testing of unique combustor concepts required extensive pressure and temperature instrumentation for effective performance analysis. These requirements have been met by the following:

- o Direct-display pressure gages, manometers, and temperature readout equipment
- o Computerized static data acquisition system
- o Digital-to-analog data output
- o Quick-look (Silvertone) data display of test data including various routines for calculation of flows, temperature rise, etc.

The central digital data acquisition system is built around a SEL 840 MP computer. The SEL 840 system processes incoming data in real time and transmits the answers to the test cell site for visual display so that test stand personnel can observe the current or past configuration operating conditions. The SEL 840 system is linked with an IBM 370/168 computer which is used for data storage and processing. The digital data acquisition system eliminated most of the hand recording of data and provided a fast, efficient, and accurate means of obtaining final test results.

A 48-port, 4-channel pressure scanning system for recording of burner pressures was used. This unit is a differential pressure measuring system using four 0 to 345 kPa (0 to 50 psia) pressure transducers, sensing pressures on 47 ports of the scanning valve. A precise pressure is connected to both sides of the pressure transducer via the forty-eighth port.

Digital data acquired by the SEL data acquisition system is transferred to an IBM model 370/168 computer where it is stored on disk. These data are converted to engineering units, numerous calculations are performed, and the results are displayed on an IBM model 2260 scope in the SEL data acquisition center and the combustion facility via closed circuit television for quick-look analysis of the rig operation by the test engineer. Such calculations as

airflow, fuel-air ratio, average burner inlet and outlet pressures, inlet flow factor, emissions, and burner outlet temperature pattern are displayed at the test site approximately 1 minute after the data are acquired.

TEST SECTION

The combustor test section, shown in the test rig installation drawing, Figure 36, adapts to an existing DDA facility supply and exhaust system with conventional rig hardware sections. The combustor housing is equipped with three variable geometry actuator systems, instrumentation, ignition, fuel, and rig control systems. The rig design permits combustor concepts to be quickly and simply modified. The independent, remotely actuated variable-geometry controls of the air staging to each combustor section allowed testing of numerous combustor configurations (airflow splits) without removing the combustor from the rig.

The air assist fuel nozzle was supplied with independently controlled high pressure air. Fuel flow rate and variable geometry movement were remotely controlled from the test cell control room.

Instrumentation

Instrumentation for this program included the items shown in Table VII.

Inlet instrumentation for total pressure and temperature used standard DDA probes at two circumferential locations each as shown in the rig installation drawing. Combustor outlet temperatures were measured using five probes (with four having five elements and the fifth with six elements) located in the combustor exit instrumentation plane as shown in Figure 37. These probes used a platinum-platinum/rhodium thermocouple junction.

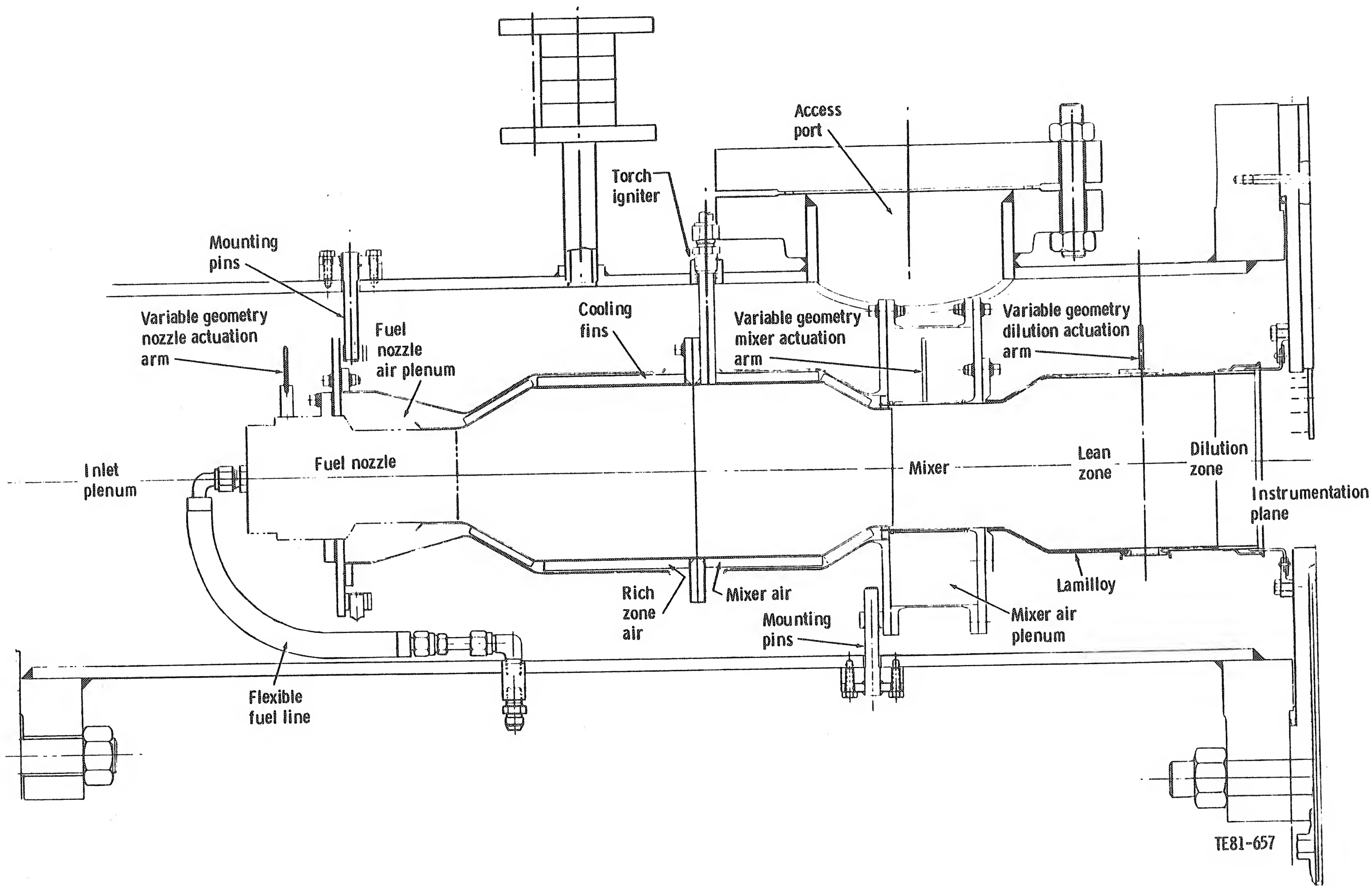

Figure 36. - Rig installation drawing.

Table VII.
Test instrumentation.

Parameter	Number	Comments
Airflow	1	ASME std orifice
Fuel flow	2	Flo-tron and metering pump
Skin temperature	33	C-A thermocouples
Gas analysis	25	5 rakes, 5 depths* commonly manifolded
Combustor outlet temperature	26	Pt-Pt 13% Rh T/C's 4 at 5 depths 1 at 6 depths
Inlet temperature	2	I-C T/C's
Inlet total pressure	2	1 depth each
Liner static pressures	10	

*Gas analysis probes could alternately provide outlet total pressure

The gaseous emission probes sample five depths at equal areas and are water cooled as shown in Figure 38. These probes are manifolded to a common heated line, which transfers the exhaust sample to the DDA-supplied gas sampling and measuring equipment described below. The probes also can be used for combustor outlet total pressure measurement.

The variable geometry control mechanisms are shown in the rig installation drawing. Position readout of this control system in concert with combustor calibrations provided the necessary data to define geometric definition and airflow splits of each combustor test configuration.

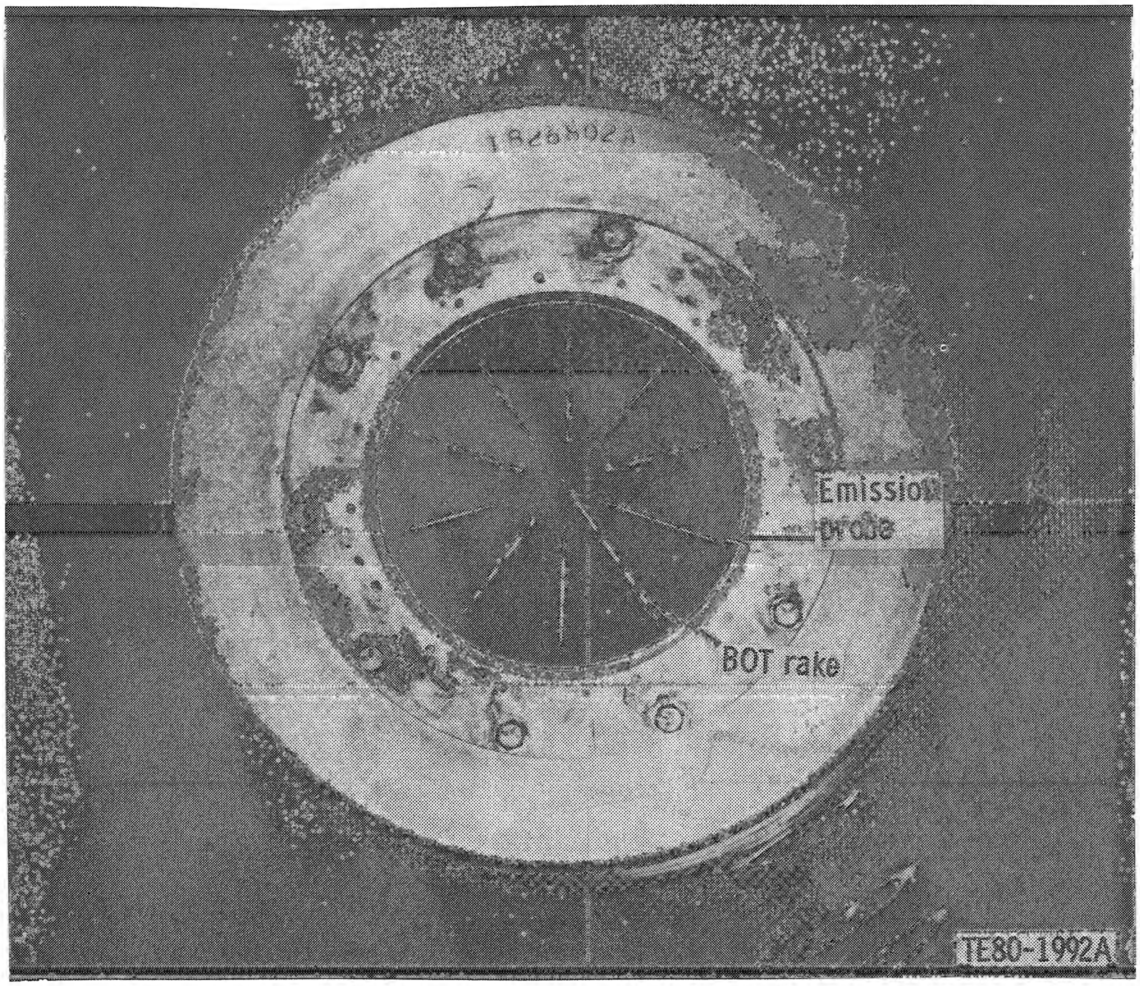

Figure 37. - Outlet temperature and emissions probes installed in test rig.

The locations of the temperature and pressure instrumentation for the Concept I combustor are shown in Figures 39 and 40, respectively. Because of the influence of fuel properties on combustion liner durability (Refs. 17,18), special emphasis was given to monitoring combustor metal temperatures. An abundance of skin thermocouples is located along the liner to monitor the integrity of the hardware during testing. There are a total of thirty-three liner thermocouples at twelve axial locations. The regenerated inlet air temperature to the rich and quench zones was also measured. The hot gas static pressure within the liner was recorded at three axial locations in addition to the nozzle and quench mixer cavity pressures.

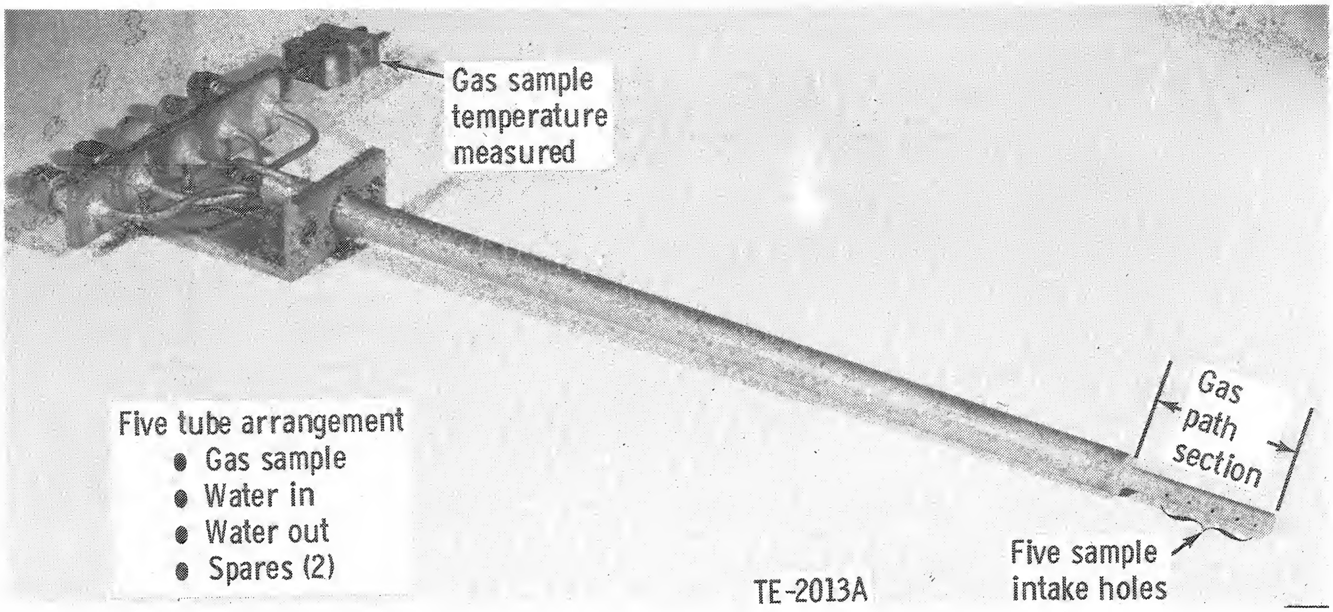

Figure 38. - Gas sampling probe.

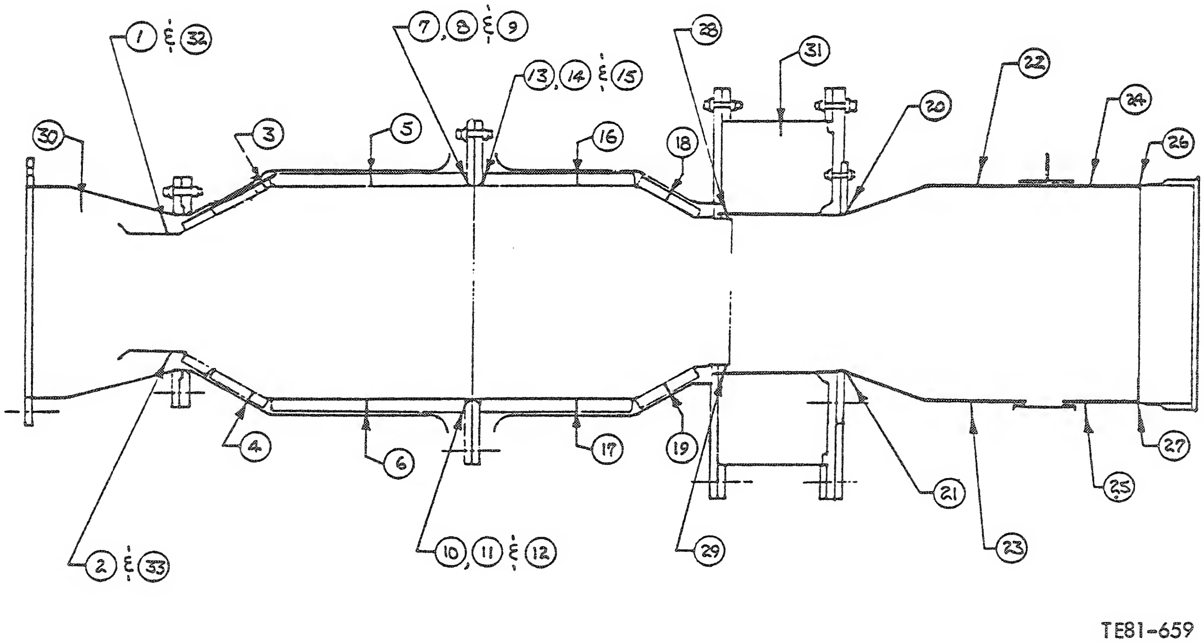

Figure 39. - Concept I combustor temperature instrumentation.

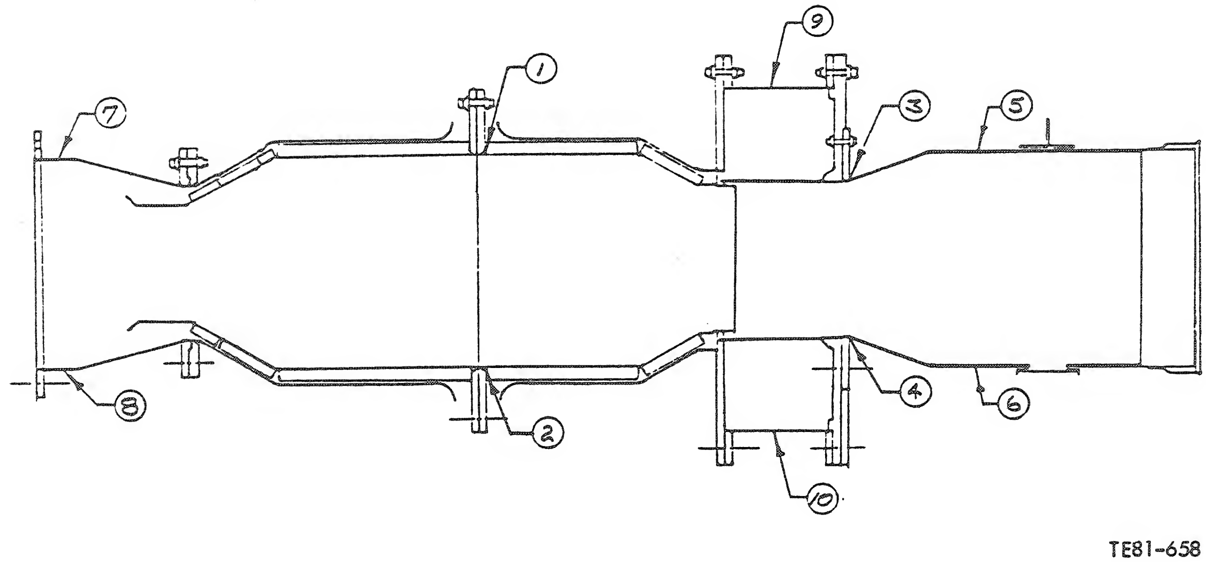

Figure 40. - Concept I combustor pressure instrumentation.

Exhaust Gas and Smoke Measurement System

For this combustor development program an on-line exhaust gas measurement system was utilized, which included the exhaust gas composition measurement instruments listed in Table VIII.

The SEL acquisition system converted the on-line emissions signals to appropriate units and calculated a fuel-air weight ratio from the exhaust gas composition measurements. This allows an on-site check of the gas sampling validity.

Figure 41 shows a schematic of the smoke measurement system used in this program. This smoke measurement method is in agreement with the SAE recommended practice (Ref. 19).

Table VIII.

Exhaust gas sampling instruments.

Carbon Monoxide (NDIR-Beckman Model 865)

Ranges--ppm	Accuracies--%
0 to 100	±2 (full scale)
0 to 500	±1 (full scale)
0 to 2500	±1 (full scale)

Oxides of Nitrogen (CL-TECO Model 10A)

Ranges--ppm	Accuracies--%
0 to 2.5	±1 (full scale)
0 to 10	±1 (full scale)
0 to 25	±1 (full scale)
0 to 100	±1 (full scale)
0 to 500	±1 (full scale)
0 to 1000	±1 (full scale)

Unburned Hydrocarbons (Heated FID-Beckman Model 402)

Ranges--ppm	Accuracies--%
0 to 10	±1 (full scale)
0 to 50	±1 (full scale)
0 to 100	±1 (full scale)
0 to 500	±1 (full scale)
0 to 1000	±1 (full scale)

Carbon Dioxide (NDIR-Beckman Model 864)

Ranges--ppm	Accuracies--%
0 to 2	±1 (full scale)
0 to 5	±1 (full scale)
0 to 15	±1 (full scale)

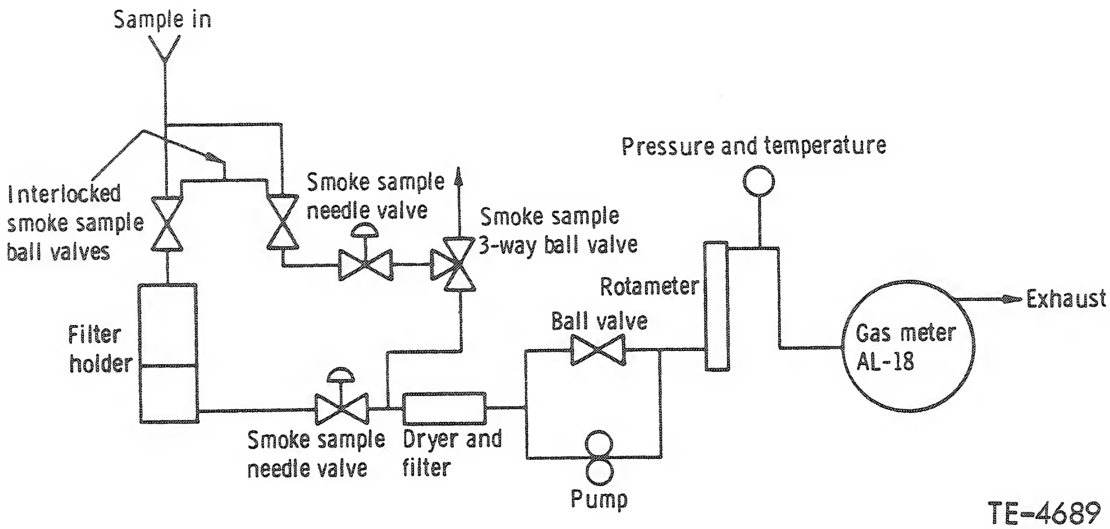

Figure 41. - Smoke sampling system schematic.

COLD FLOW CALIBRATION

Prior to the hot flow shake-down testing of the RQL combustor in the test rig, a cold flow calibration was performed to establish the aerodynamic performance of each variable geometry section of the combustor. Except for the fuel nozzle-rich zone air system, these cold flow tests were carried out in the combustor rig so that all test environment effects within the rig might simultaneously be calibrated with the variable geometry sections.

Due to the low airflow rates involved, the fuel nozzle-rich zone air system was calibrated on a separate flow bench. For this calibration the forward portion of the combustor rich zone was removed from the combustor at the center flange joint. This forward section was installed over the inlet of a subambient airflow rig. The fuel nozzle was installed in its proper position at the upstream end of the flow rig, thus sealing the rich zone air system, forcing all of the air to take the same flow path that the rich zone air will take during hot flow testing. The test setup is diagrammed in Figure 42.

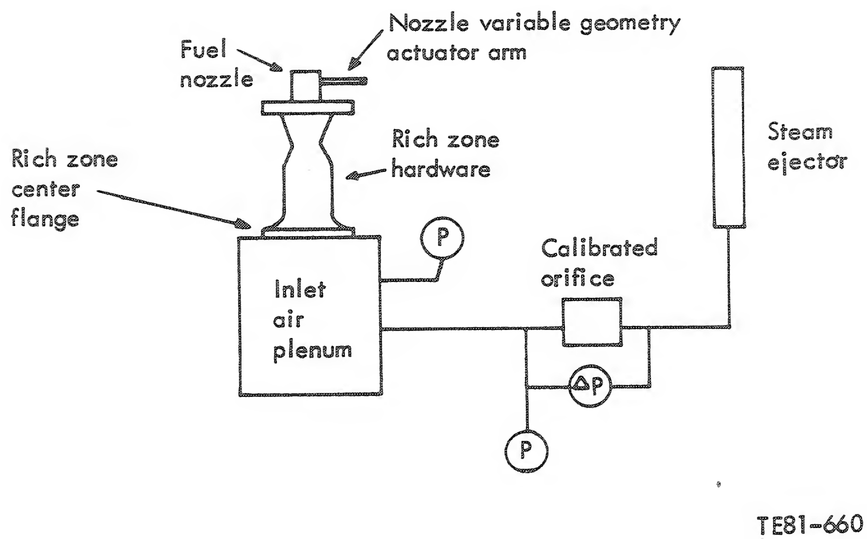

Figure 42. - Fuel nozzle airflow calibration setup.

A series of pressure drops was established on the flow rig at five variable geometry positions of the fuel nozzle from full closed (0% open) to full open (100% open). From these data the flow map (Figure 43) for the rich zone system was generated.

To determine the flow map for the mixer, the forward portion of the rich zone was reinstalled on the combustor. The lean zone cooling air, dilution holes, and aft cooling air holes were taped closed and in this configuration the combustor was installed in the test rig. A parametric set of airflow and pressure drop data points was recorded for the various combinations of both the mixer variable geometry and the fuel nozzle variable geometry. The mixer flow map, Figure 44, was then computed by subtracting the calibrated nozzle-rich zone flows from the nozzle-mixer combination.

Once the mixer system flow map was determined, the process was repeated with the lean zone-dilution zone air flow passages opened. The dilution zone variable geometry was calibrated by cold-flow testing a three-dimensional matrix of points having various combinations of each of the three variable geometries (nozzle, mixer, and dilution). The fuel nozzle flow and the mixer flow

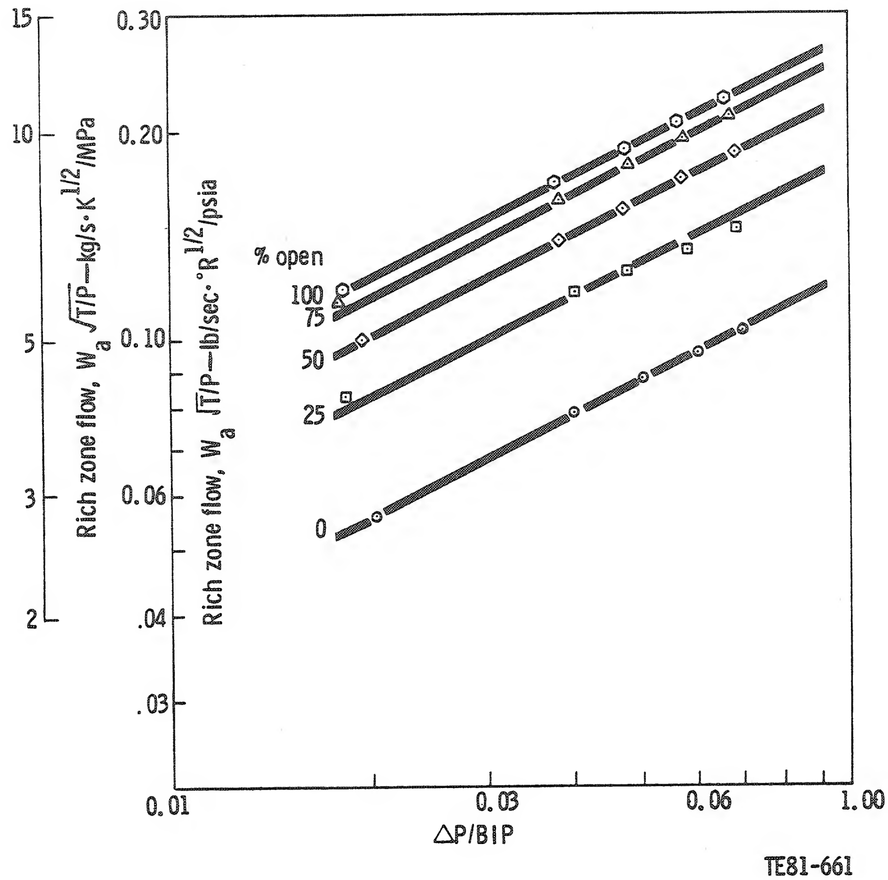

Figure 43. - Variable-geometry fuel nozzle flow map.

(already determined) were subtracted from measured total flow, resulting in the flow characteristic of the dilution zone variable geometry system, Figure 45. These experimentally determined airflow characteristic maps were used throughout the program to determine variable geometry settings for each data point to be run prior to testing, as well as for post-test analysis to assess the operating point actually tested.

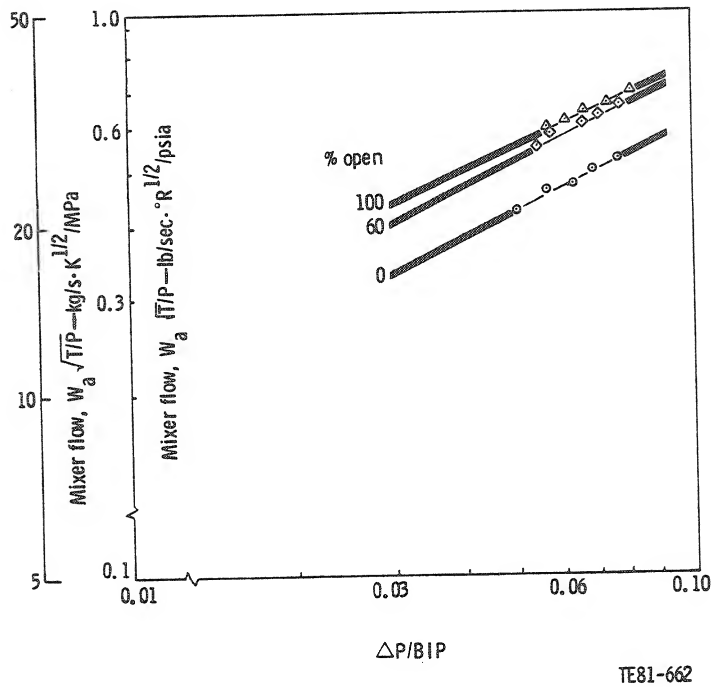

Figure 44. - Variable-geometry mixer flow map (lean zone equivalence ratio equal to 0.40).

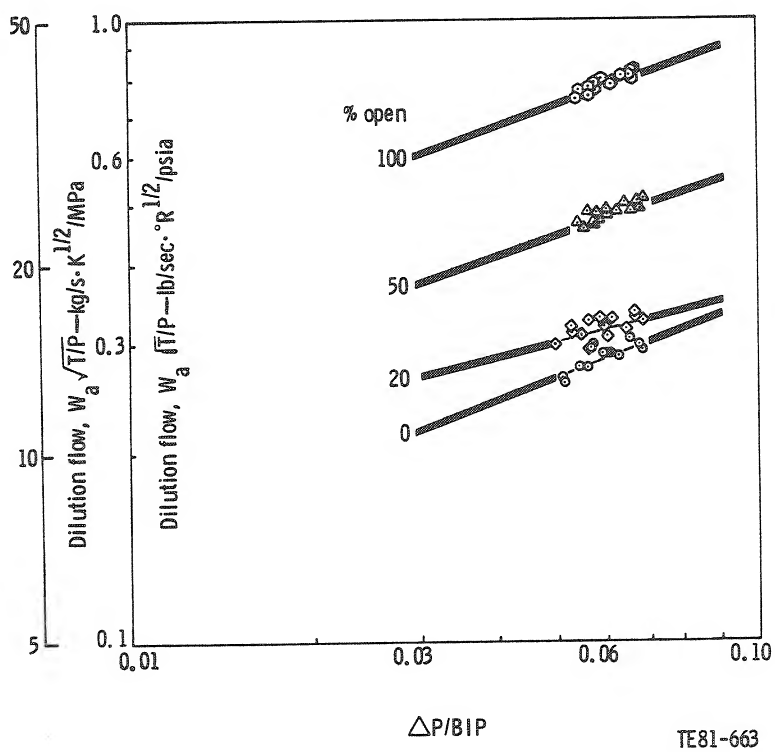

Figure 45. - Variable geometry dilution positioning.

V. TEST RESULTS

A vast amount of test data was recorded during this combustor technology program. Although three combustor concepts were designed and fabricated the major development and test effort was spent on the Concept I--rich/quench/lean combustor. This section presents the significant test data on the RQL combustor and the Concept III--lean/lean combustor. Table IX summarizes the number of test points taken for the major divisions of the testing effort.

Table IX.
Summary of test data points recorded.

Concept	Combustor	Test type	Fuels*	Data points	Total data points
I	RQL	Development	A,B,C	209	
		Performance	A,B,C	174	
		Parametric	A,B	211	594
II	Preburner RQL	-	-	---	---
III	Lean/lean	Performance	A	11	11
			Total data points		605

*A - ERBS
B - Petroleum residual, RESID
C - Synthetic coal derived liquid SRC-II

CONCEPT I--RICH/QUENCH/LEAN

Combustor performance and emission data for the Concept I--RQL combustor are presented in this section. Because this was a technology generation program it is important to review pertinent items that occurred during combustor development in addition to discussing the results from the final configuration of the combustor hardware. Thus, the operational problems uncovered and solved during the RQL combustor development will be discussed, and the final performance and parametric test results will then be presented.

Development Testing

The objectives of this segment of the combustor technology program were to evaluate rich and lean zone equivalence ratio effects for the three base-line fuels against performance, emission, and liner durability goals. Development test results reported in this section are for operating conditions at or near maximum continuous power operation for the Model 570-K industrial gas turbine engine. Since this is the highest continuous power level for the engine, and since the engine spends much of its operating life at this point, this condition was the design point for all of the combustors in this program. Thus the NO_x and smoke emissions produced at this level are most important. Testing over the operational range of the engine was conducted later in the program and will be presented in the Final Test Data portion of this section.

Initial testing of the Concept I--RQL combustor on ERBS fuel revealed two deficiencies in the operation of the combustor over the range of parameters of interest. Trying to operate the combustor over a wide range of rich-zone equivalence ratios (1.2 to 2.5) resulted in a severe buildup of carbon in the rich zone, as seen in Figure 46. The carbon was generated when the equivalence ratio in the rich zone increased above approximately 2. The cause was determined to be excessively rich operation in a very "lazy" zone. The limited quantity of air required to achieve the high equivalence ratios, recalling that design fuel flow is maintained, coupled with combustor temperatures significantly lower than stoichiometric, results in reduced gas velocities. The consequences of low gas velocities are extreme rich zone residence times, unstable aerodynamic flow patterns, and nonuniform mixing. All items contribute to the carbon deposits. As a result of the carbon formation, operation at high equivalence ratios was determined to be impractical and subsequent testing was limited to equivalence ratios less than 2.

A second area requiring immediate attention was overheating of the liner in the fuel-nozzle area and the forward portion of the rich zone. Examination of the liner indicated that air leaking past the nozzle and, possibly, the torch igniter initiated local stoichiometric combustion zones when interacting with the fuel rich mixture exiting the fuel nozzle. The high temperature burning

Figure 46. - Carbon build-up in dome of RQL combustor operating at rich zone equivalence ratios above 2.0.

near the liner wall overloaded the extended surface convection cooling system. Constant monitoring of rich zone metal temperature thermocouples in the forward portion of the rich zone was required to limit measured metal temperatures below 1340 K (1952°F). The overheating of the wall in the rich zone limited the operating conditions to an inlet air temperature of approximately 450 K (350°F). As development proceeded some data were obtained at 580 K (584°F) with ERBS fuel, but in general the testing was restricted to the lower inlet air temperature.

The overheating in the rich zone was overcome by incorporating several design modifications. The first affected the air leakage past the fuel nozzle. The RQL design supported the inner shell (flame tube) from a split line located near the midpoint of the rich zone. The flame tube thermal growth was accommodated by a sliding fit over the fuel nozzle barrel forward and by a sliding fit at the entrance to the mixer aft. The aft portion of the rich zone never required modification from the initial design. Wall temperatures seldom exceeded 900 K (1160°F) in this area. The sliding fit around the fuel nozzle, however, allowed inlet air to be injected into the reacting fuel rich mixture. This leakage air entering the rich zone tended to stay on or near the diverging flame tube wall and react at near stoichiometric conditions.

The torch igniter, located in the conical dome of the rich zone, required sealing ferrules on both the flame tube and the cooling/support cone surfaces. Even with a close tolerance between the matching parts some air leaked past the inner ferrule. Also, the blockage to several cooling air channels caused by the presence of the torch igniter itself degraded the cooling effectiveness locally. In addition to the blockage and air leak problems, the spray pattern from the fuel nozzle was nonuniform.

It became clear from the test data that for a successful rich zone to function there must be:

- o No air leakage
- o Circumferentially uniform and effective convection cooling
- o Uniform fuel nozzle patternation
- o Strong swirl for recirculation and intimate mixing

Modifications were incorporated into the rich zone hardware to overcome these operational problems. To prevent air leakage past the torch ferrules into the dome of the rich zone and to eliminate blockage of any forward cooling channels, the torch igniter location was moved from the rich-zone dome to just aft of the rich zone support flange. As shown in Figure 47, the new location of the ignitor ferrule was upstream of the rich-zone cooling fins so that no cooling air channels were blocked. There is little thermal growth differential at the rich zone flange so a rigidly attached ferrule was used.

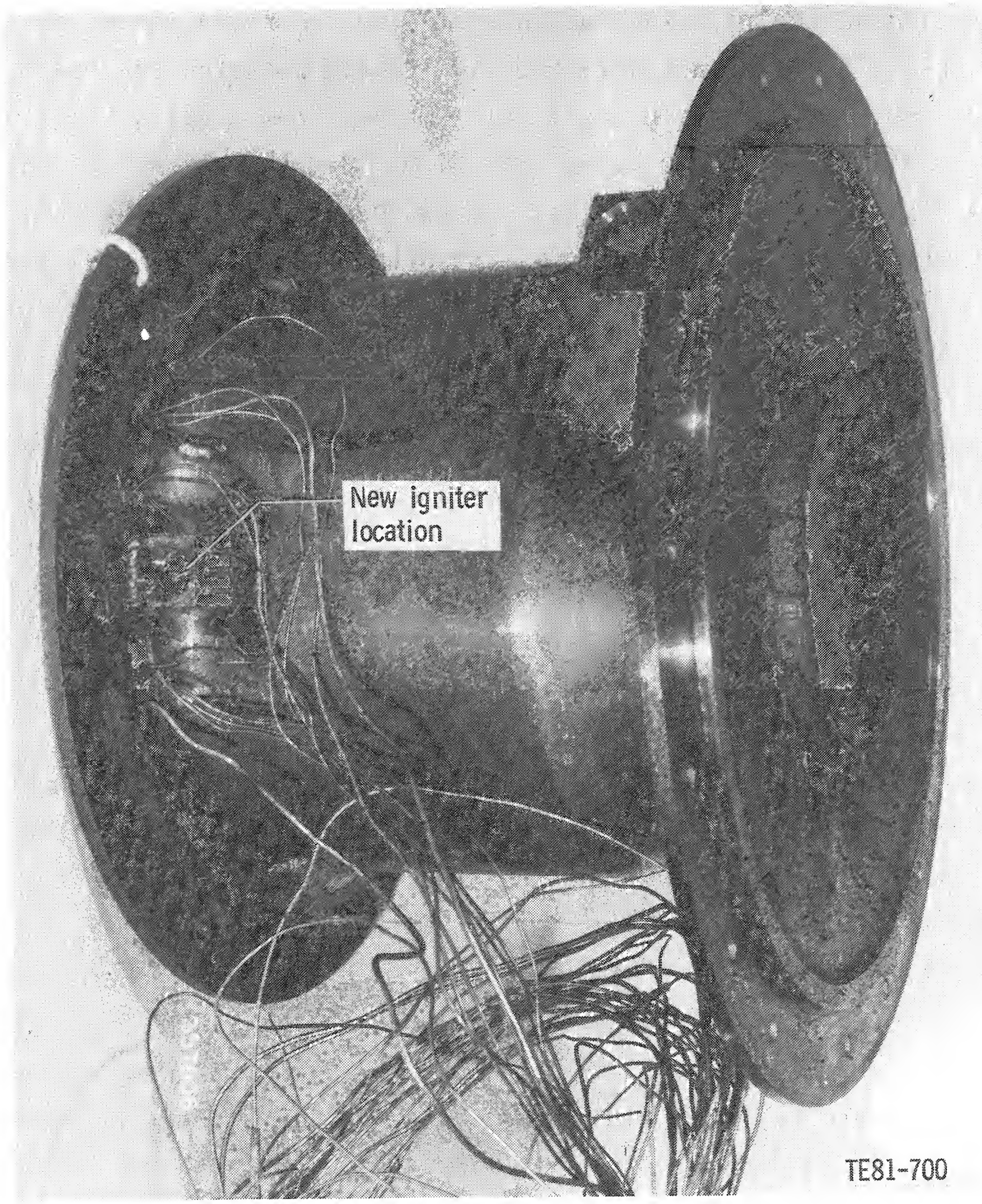

Figure 47. - Back half of rich zone showing new torch igniter location against flange.

To reduce air leakage, a snug fit was used between the torch barrel and the ferrule. Forcing the torch tip against a shoulder at the bottom of the ferrule further reduced air leakage. Radial thermal growth maintained the contact on the ferrule shoulder as the combustor warmed up after ignition.

The cooling effectiveness and mechanical integrity of the forward rich zone was improved through a series of changes. The cooling fins were reduced in height from 7.6 to 5.1 mm (0.300 to 0.200 in.) to increase the heat transfer from these surfaces. The flame tube was changed from 0.81 mm (0.032 in.) thick Hastelloy X alloy (AMS 5536) to 1.52 mm (0.060 in.) thick Haynes 188 alloy (AMS 5608). The Haynes 188 alloy exhibits higher strength at elevated temperature than the Hastelloy X alloy, thus providing added margin to the cooling scheme.

The axial spacing between staggered fin sections on the conical dome (Figure 48) was increased from 1.5 to 3.0 mm (0.060 to 0.120 in.). Because of the reducing diameter of the conical dome, the initial design used only 48 fins near the nozzle versus the 96 on the remainder of the assembly. Here, again, a change was made, increasing the number of fins from 48 to 64 and indexing them to cause minimum blockage to the upstream cooling flow.

In general, the three variable-geometry systems exhibited minimal mechanical problems. The variable-geometry fuel nozzles functioned quite well; however, there was a tendency to bind when hot and fully closed. The mixer and dilution variable-geometry systems were both modified to reduce the design clearance between the bands and the flame tube, since neither zone operated as high in metal temperature as expected. Thus, there was excessive thermal gap initially designed into each band. The mixer band was also reinforced circumferentially with a metal stiffening ring to reduce the flexing of the band with movements of the single actuator. Mixer band concentricity was improved by adding containment rings at both edges. These containment rings also reduced air leakage under the mixer band edges.

Each of the three fuels created its own special problems during the development testing. Handling the coal-derived SRC-II fuel produced a chemically hazardous situation for technicians who had to work on the fuel system when this fuel was being used. A fuel of this toxicity requires special safety clothing and equipment for test personnel who make any of the usual adjustments or minor repairs in the test cell.

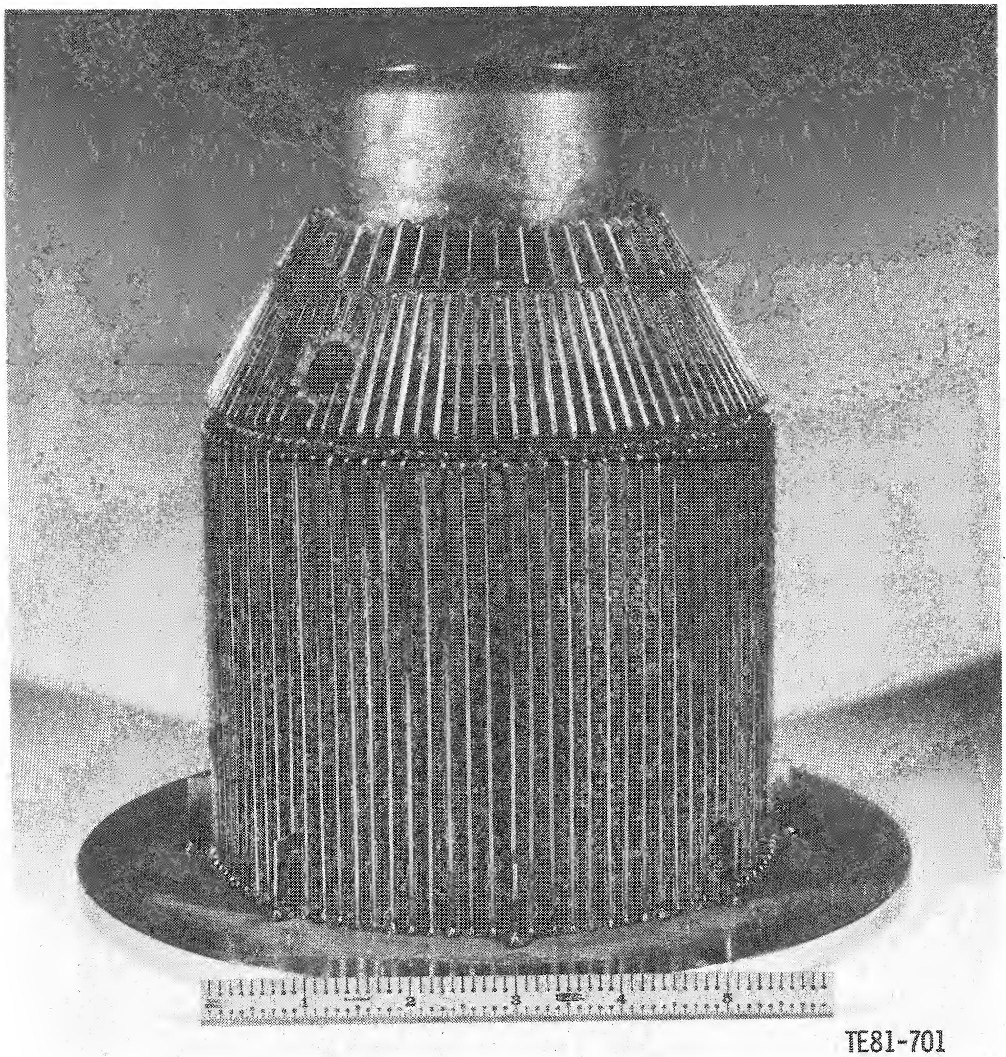

Figure 48. - Initial forward half of rich zone with cooling air cover removed, showing extended area cooling fins.

The RESID fuel has a very high pour point and extremely high viscosity at room temperatures. Principle difficulties with this fuel stemmed from the elevated temperatures to which this fuel had to be heated and maintained in order to reduce the viscosity so that it could be handled in lines, pumps, metering systems, and flow measuring systems. With this in mind, it was imperative that the RESID fuel not be left in any fuel lines after daily shutdown of the test systems and equipment. To avoid plugging the fuel system with cold RESID fuel, the fuel system was purged with ERBS fuel to clear the lines by disolving or carrying away the hot RESID fuel. The RESID fuel progressively blocked the standard 3-micron fuel system filters in the delivery lines to the rig test

section. The 3-micron filters were replaced by 10-micron elements to extend running time. The RESID fuel had to be continuously recirculated through 10-micron filters when the fuel heaters were on to maintain a uniform bulk fuel temperature at 365 K (200°F). Testing time was limited to the supply in the run tank. Adding fuel during the test resulted in a stratified mixture and pulsations in the fuel system.

Testing with the RESID fuel also required cleaning the variable geometry fuel nozzle after each day's testing. Figure 49 shows the nozzle fuel distributor plate prior to testing with RESID fuel, and Figure 50 shows the same nozzle after a day's test. The flow number ($W_f/\sqrt{P}$) for the clean nozzle was 153-158 kg/s/MPa (28-29 lb/s/psi). After testing on RESID fuel, flow numbers were as low as 55 kg/s/MPa (10 lb/s/psi) and usually at or below 109 kg/s/MPa (20 lb/s/psi), even after purging the entire fuel system by operating on the ERBS fuel before shutting off the fuel to the combustor.

An operational problem also occurred with the ERBS fuel during the test. Levels of increased FBN were obtained for all three fuels by adding varying amounts of pyridine to the fuel in an on-line mixing chamber. The particular pyridine used was 2-vinylpyridine, C_7H_7N. In two instances, and only two, the addition of pyridine to the ERBS fuel produced a sizable amount of reaction product or precipitate having the look, feel, and resilience of "rubber bands". Both times this phenomenon occurred, the test was immediately terminated and the fouled stainless steel fuel lines were replaced. The pyridine vendor was contacted and shown the precipitate, but he could shed no conclusive light on the cause. On both occasions when the precipitate was formed, the pyridine system had not been used for as long as four to six weeks. In each case, after the fouled lines were replaced, there were no further occurrences during that test series encompassing several days of fuel-pyridine combustor testing. To date, no cause has been identified for the precipitate.

Most of the development testing was performed with the rich zone equivalence ratio greater than 1.0. On one occasion when testing with the RESID fuel, the RQL combustor was operated with the rich zone actually leaner than stoichiometric to establish whether it was leaking air past the fuel nozzle that

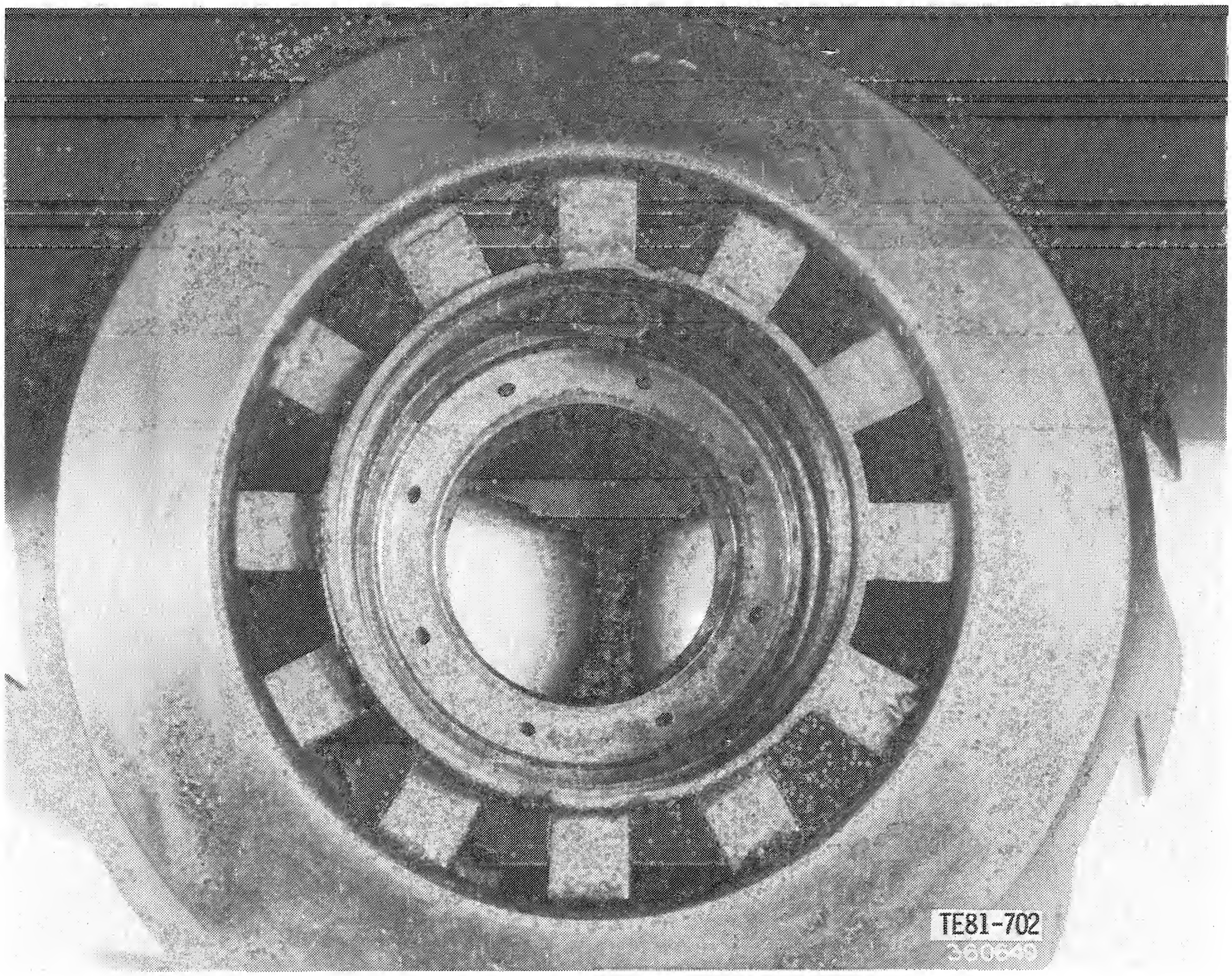

Figure 49. - Air blast fuel nozzle fuel distributor clean, prior to test.

reacted with the rich mixture to produce stoichiometric combustion along the wall and thus high metal temperatures. Eight test points were taken with the rich zone equivalence ratio varying between 0.85 and 0.95 and in each case the high rich-zone metal temperatures near the fuel nozzle decreased 55 to 80 K (100 to 150°F), verifying that the air was leaking past the fuel nozzle. Exhaust emissions were also recorded for each of the data points. The corrected nitrogen oxides are presented in Figure 51, and show the typically high NO_x levels (600 ppm) for the high burner inlet temperature (BIT), lean equivalence-ratio reaction zone (ϕ = 0.9).

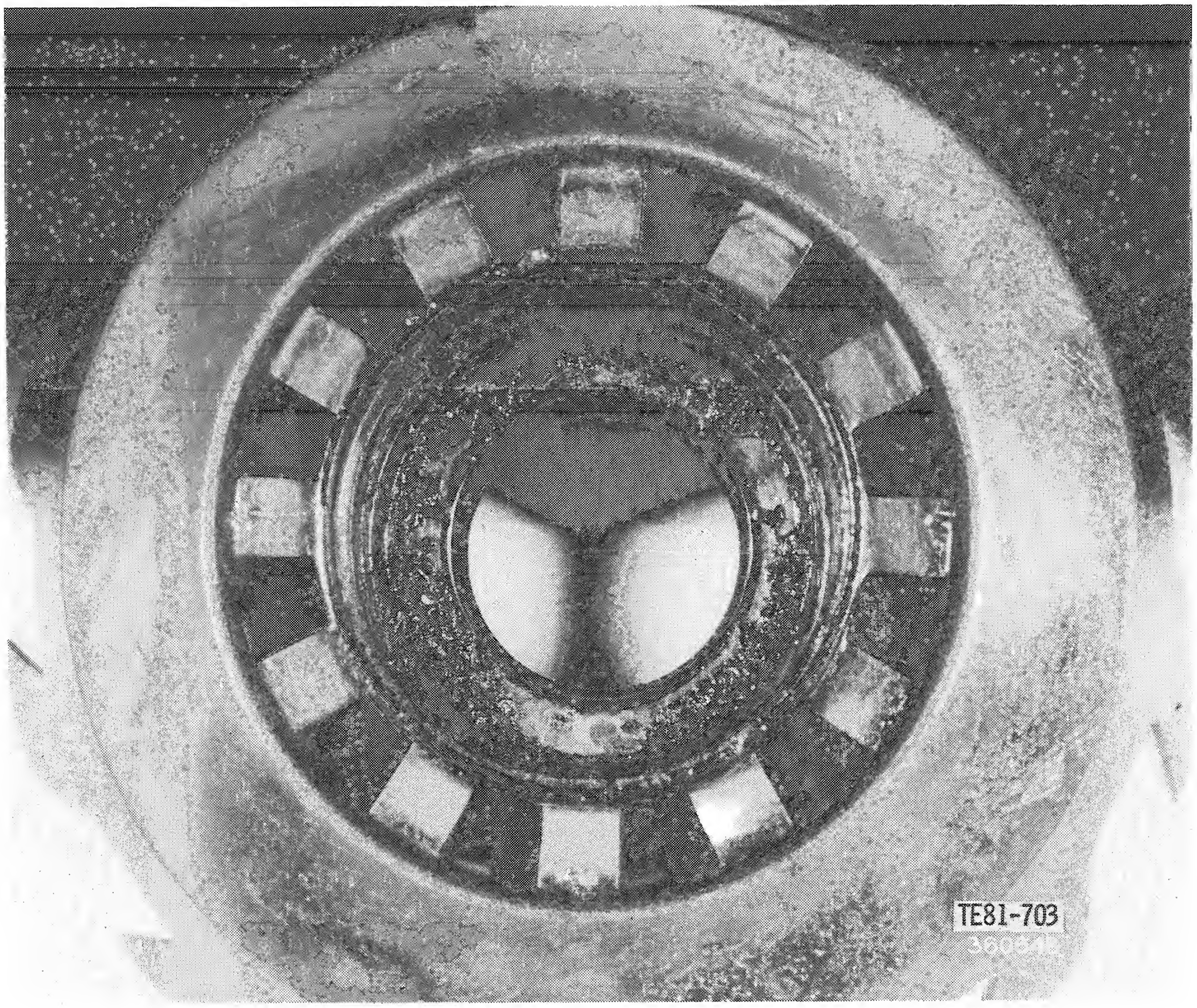

Figure 50. - Air blast fuel nozzle fuel distributor fouled, after test.

Exhaust emissions were measured all during the Concept I-RQL combustor development. These emission results, as well as the durability problems encountered, guided the design of modifications made to the combustor during this period. The data presented in this section constitute summaries of the emissions for all three test fuels near the maximum continuous power operating condition of the Allison Model 570-K engine.

Emission results as a function of rich zone equivalence ratio are shown in Figure 52 for the three test fuels. (Note that parametric variation in equivalence ratio inherently includes variation in rich zone residence time and swirl strength.) The ability of the combustor to achieve low NO_x with significantly different fuels and levels of FBN is clearly demonstrated in

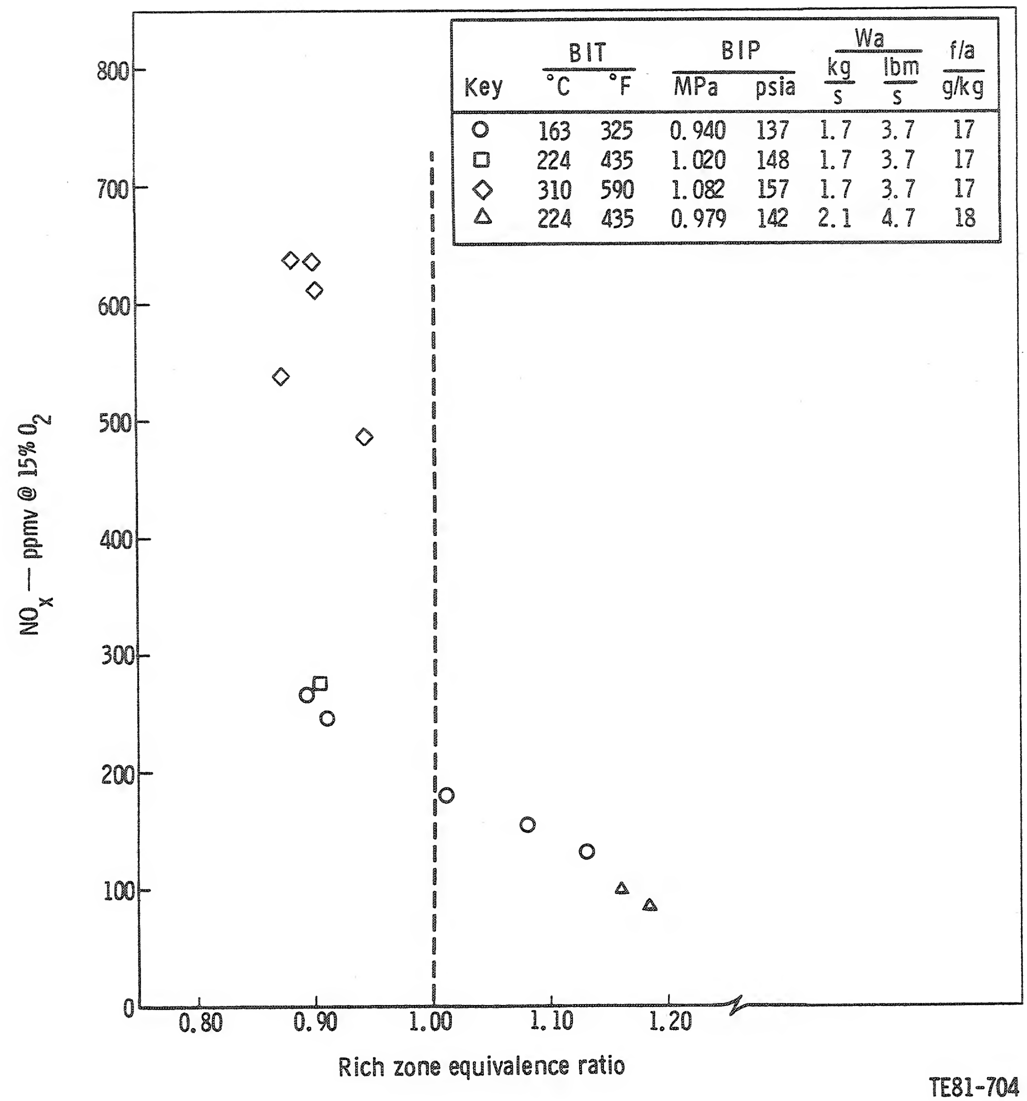

Figure 51. - RQL combustor NO_x emissions when operating with rich zone on lean side of stoichiometric.

Figure 52. Because the levels of FBN in the RESID and SRC-II fuels exceed 0.25 wt %, the NO_x goal under this DOE/NASA program was 140 ppm. (The EPA Stationary Gas Turbine NO_x standard for the Allison Model 570-K is 230 ppm.) Unburned hydrocarbon emissions from the combustor are not presented since the levels measured at maximum continuous power were all below 20 ppm and nearly half the measurements were below 5 ppm. To achieve the goal of 99% combustion efficiency, CO emissions must be kept below 970 ppm at maximum continuous operation (310 ppm at idle). The goal for exhaust smoke was a maximum smoke number of 20 SAE.

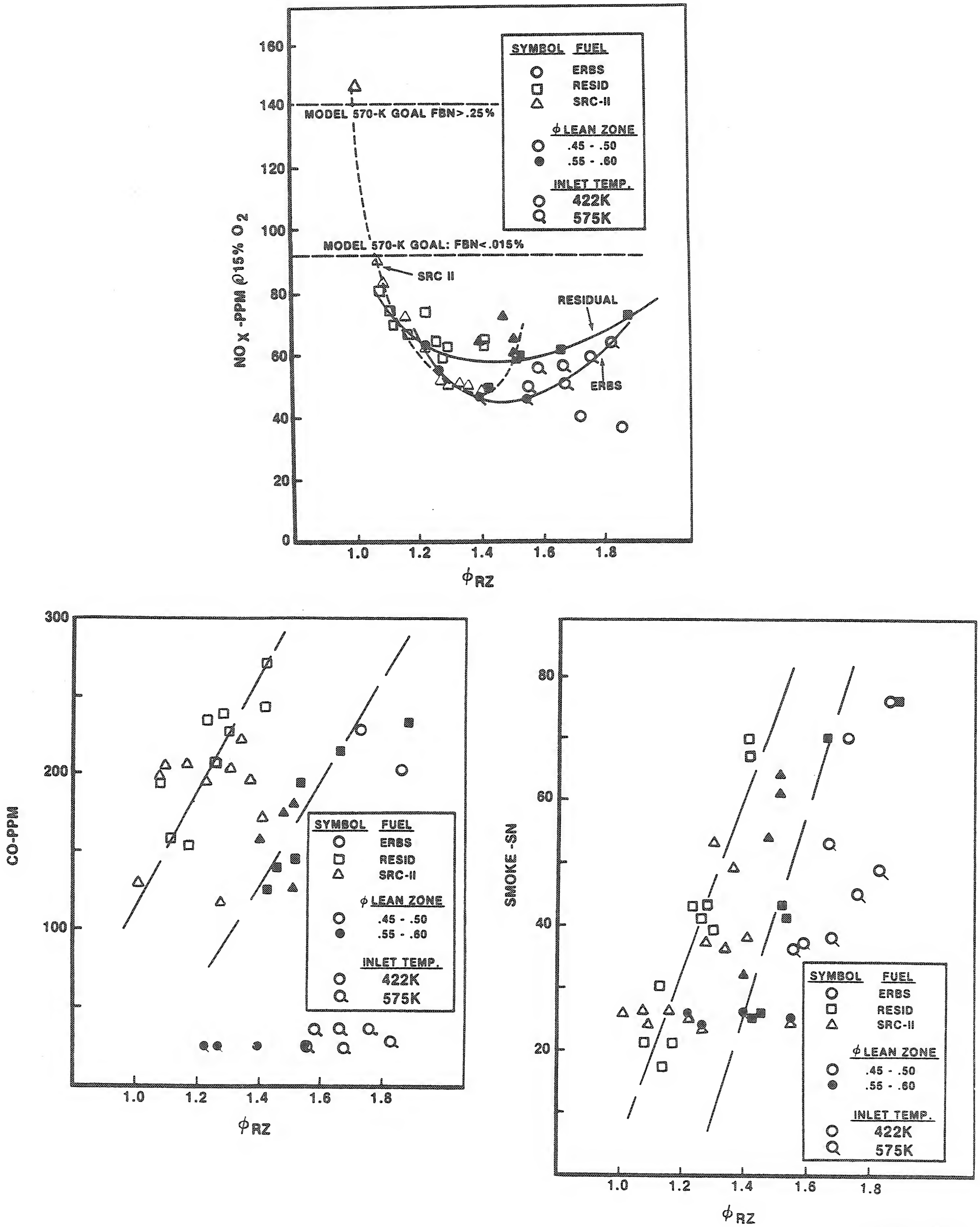

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Figure 52. - NO_x, CO, and smoke emissions vs rich zone equivalence ratio for development RQL combustors.

The emissions data shown in Figure 52 were measured at a variety of different conditions. There are three different fuels represented: ERBS, RESID, and SRC-II. Next there are two combustor inlet temperatures plotted: 422 K (300°F) and 575 K (575°F) (flagged points). Finally there are two ranges of lean zone equivalence ratios and total mass flows represented: lean zone equivalence ratio ranges of 0.45 to 0.50 and 0.55 to 0.60, with total mass flows of rated airflow and 125% rated airflow (20% reduction in residence time). However, for all tests the overall fuel air ratio is maintained at maximum continuous power specification. The variations in both rich and lean-zone equivalence ratios were obtained with adjustments to the combustor variable geometry. For all test points, a 6% system pressure drop was maintained while varying both zone equivalence ratios and total mass flow. Inlet temperatures were below the normal operating level of 622 K (661°F) to avoid high metal temperatures in the combustor rich zone hardware. The temperature of the rich zone hardware varied directly with rich zone equivalence ratio. As equivalence ratio increased, cooling air decreased, thus reducing cooling effectiveness of the regenerative/convective cooling system.

Even though the data in Figure 52 have considerable scatter, trend lines drawn through the NO_x data for each base-line fuel show a minimum in the NO_x curve in the region of 1.4 rich-zone equivalence ratio. Only the ERBS fuel was operated at two different inlet temperatures. Comparing the ERBS data illustrates how NO_x increased while CO and smoke decreased as inlet temperatures were raised.

NO_x emissions appeared to be controlled only by inlet temperature and the rich zone equivalence ratio. Changes in the lean or dilution zone had no observable effect on NO_x, even though an effect was expected. Carbon monoxide emissions and smoke, on the other hand, were influenced significantly by both rich zone and lean zone equivalence ratio, as well as by combustor inlet temperature. Both CO and smoke varied directly with rich zone equivalence ratio and inversely with lean zone equivalence ratio. The higher temperatures in the lean zone due to either a higher equivalence ratio or a higher inlet temperature increased the CO reaction rate and resulted in lower CO in the combustor exhaust.

To simultaneously achieve the NO_x and smoke goals, it appeared that the minimum NO_x achieved must be compromised. Because of the sizable margin beneath the NO_x goal and the need to significantly reduce the smoke, subsequent rich-zone combustor stoichiometry should be leaned to the 1.2 to 1.3 equivalence ratio range to produce less smoke while accepting some increase in NO_x emissions. Also, it appeared desirable to operate at higher lean-zone equivalence ratios, in the range of 0.60 to 0.65 (also with the possibility of increasing the NO_x) to consume more of the smoke in the lean zone. This NO_x versus smoke trade-off is indicated in Figure 53, where the data represent rich-zone equivalence ratios of 1.4.

Subsequent to the recording of the test data presented above, a series of modifications, previously detailed, was made to the rich zone combustor hardware. These modifications included:

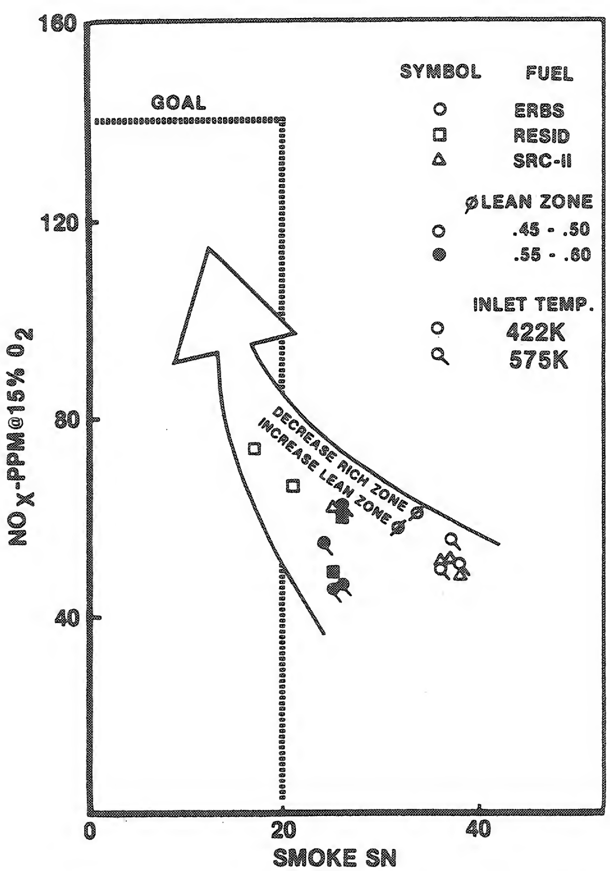

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Figure 53. - NO_x vs smoke at rich-zone equivalence ratio for minimum NO_x.

- o Moving the torch igniter from dome to just aft of center flange to remove air leakage and cooling flow blockage in the dome.
- o Changing the rich zone inner shell in front half from Hastelloy X (AMS 5536) material 0.8 mm (0.032 in.) thick to Haynes 188 (AMS 5608) material 1.5 mm (0.060 in.) thick for increased high temperature integrity and mechanical strength.
- o Reducing the cooling fin height from 7.6 to 5.1 mm (0.300 to 0.200 in.) to improve heat transfer to cooling air.
- o Increasing the number of fins nearest the fuel nozzle from 48 to 64 for improved heat dissipation.
- o Increasing the axial spacing between rows of fins, from 1.5 to 3.0 mm (0.060 to 0.120 in.) to avoid blocking cooling air flow when fin sections are staggered.
- o Adding a fuel nozzle baffle either to seal the leakage path past the fuel nozzle or to direct any leaking air toward the center line where it would be entrained in the flow from the nozzle.

Test results of the RQL combustor having these modifications are presented in the following section.

Final Results

Testing of the RQL combustor final design encompassed two test series: performance testing and parametric testing. In the performance testing each of the three test fuels was used (ERBS, RESID, SRC-II). For the parametric testing only ERBS and RESID fuels were utilized. The purpose of these tests was to assess the fuel flexiblity and the operating sensitivity of the RQL combustor. Also, pyridine (specifically 2-vinylpyridine, C_7H_7N) was added to each fuel to increase the fuel nitrogen level. All test points corresponded to the combustor operating conditions of the DDA Model 570-K industrial gas turbine. These operating conditions are summarized in Table X. Inlet temperature, pressure, and airflow were matched as presented in Table X, and the fuel flow rate was maintained at the stated flows for each fuel. Thus since the RESID and SRC-II fuels had slightly lower energies or lower heating values (LHV), the outlet temperatures were somewhat lower with these fuels

than the engine rated levels. Stoichiometric fuel-air ratios were computed from each fuel's carbon-hydrogen ratio and thus rich and lean zone equivalence ratios reflected this characteristic.

Table X.
Engine/combustor operating conditions.

Engine Mode	Inlet Airflow kg/s	Inlet Temp K	Inlet Press MPa	$m\sqrt{T}/P$	Fuel flow kg/h	F/A° g/kg	Outlet temp K
Idle	0.733	445	0.359	43.01	18.51	7.09	898
50% Load	1.313	559	0.801	38.73	74.48	15.8	1150
70% Load	1.461	584	0.934	37.78	96.25	18.3	1256
Max Continuous (base load)	1.680	623	1.142	36.69	134.67	22.3	1416
Max Rated (peak load)	1.756	638	1.220	36.28	150.32	23.8	1478

Data Validation

Performance testing of the RQL combustor with each of the three fuels over the range of Model 570-K engine operation compiled 174 data points. Comparisons between mechanical and chemical fuel-air ratios for each of the three fuels are shown in Figure 54. Mechanical fuel-air ratios are determined by a Flotron flowmeter and calibrated airflow orifice measurements. The chemical fuel-air ratios are computed from measured exhaust gas samples: CO_2, CO, UHC, and NO_x. The exhaust gas sampling system derived fuel-air ratios agree within 10% of the mechanical derived values. Thus the gas samples measured from the RQL combustor liner appear representative of the exhaust gases exiting the combustor.

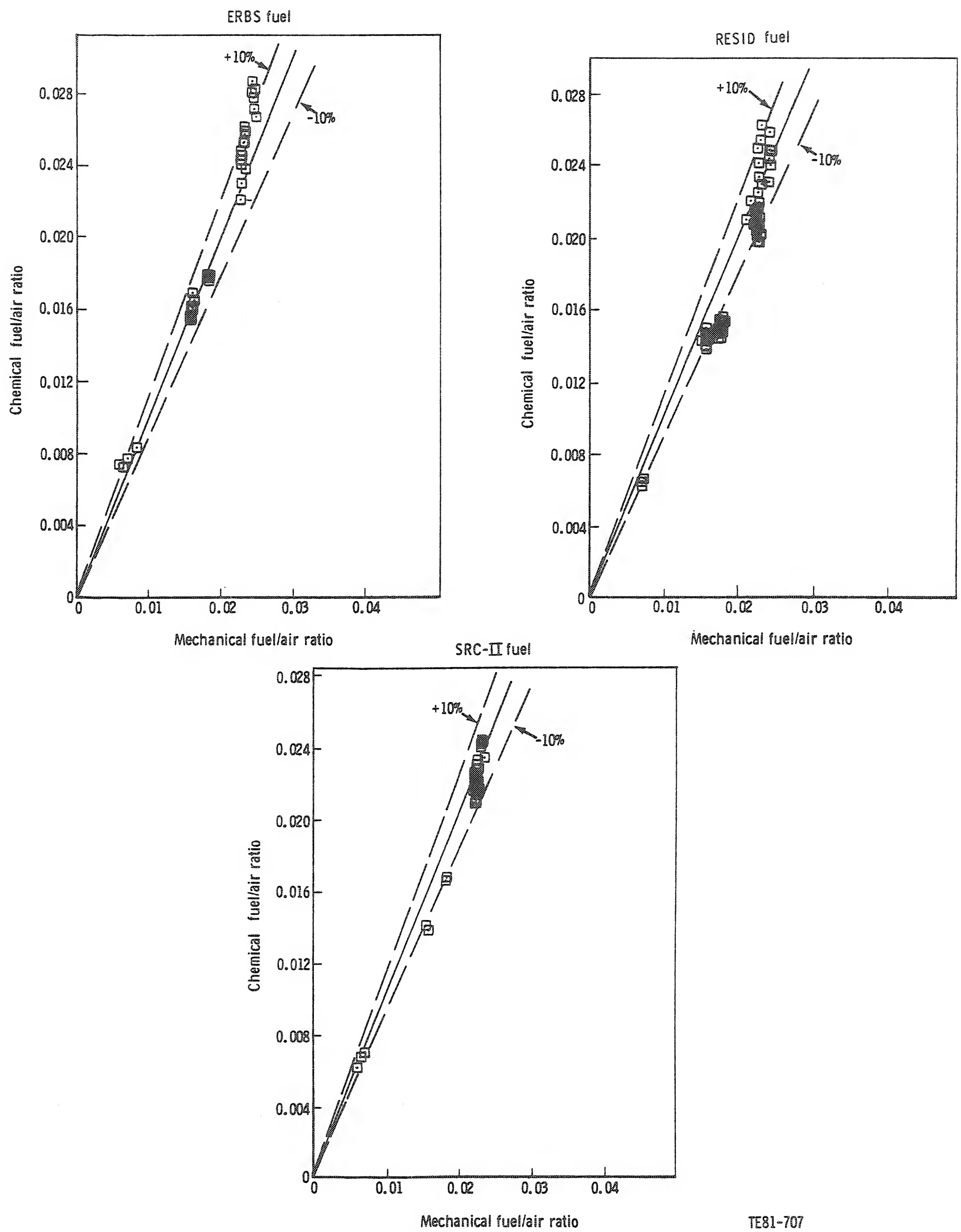

Figure 54. - Chemical vs mechanical fuel-air ratios for performance data obtained on all three test fuels.

Performance Testing

The RQL combustor was tested at five steady-state, Model 570-K engine operating conditions from idle to maximum rated power. Figures 55 to 60 show five data plots each (corrected NO_x, corrected CO, SAE smoke number, combustion efficiency, and maximum combustor liner metal temperature) with all three fuels presented on each plot for comparison. Operation of the RQL combustor at the four operating conditions above idle were well within the range of the variable geometry system, but at idle the range was quite restricted as seen in Figure 61.

To maintain equivalence ratios greater than 1.0 in the rich zone at idle the variable geometry fuel nozzle needed to be nearly closed while the mixer and dilution geometry required near full open settings. These variable geometry combinations severely reduced the system pressure drop from the usual 6% to the 3 to 4% level. With the fuel nozzle closed, the aerodynamic performance of the fuel nozzle produced poor mixing and recirculation. Also, since pressure drop was low, atomization quality was poor. It was feared that combustor damage might occur during the idle testing. Therefore, the idle performance was the last test conducted on the RQL combustor hardware, even after the parametric testing which will be subsequently discussed. Three idle test points were obtained for each fuel. Only the mixer geometry was varied to keep the rich zone as rich as possible and to increase the pressure drop to help the mixing. The idle data obtained were quite high in NO_x. Inspection of the combustor after the idle test revealed some burn-through in the dome, which probably shifted the rich zone equivalence ratio below stoichiometric (or to fuel lean conditions). This would explain the high NO_x levels measured at this condition. Modifications made during development to reduce leakages and actuation sensitivity shifted the preferred operating range of the combustor away from the idle condition. Hence, it is felt the idle data is not representative of how a preferred RQL combustor should operate.

For the power levels above idle, the RQL combustor performance was excellent. Above idle, CO emissions were below 50 ppm at 50% load and down to 20 ppm at maximum rated power. Unburned hydrocarbons were below 10 ppm for all fuels at all power levels and thus are not presented. Exhaust smoke was always below a

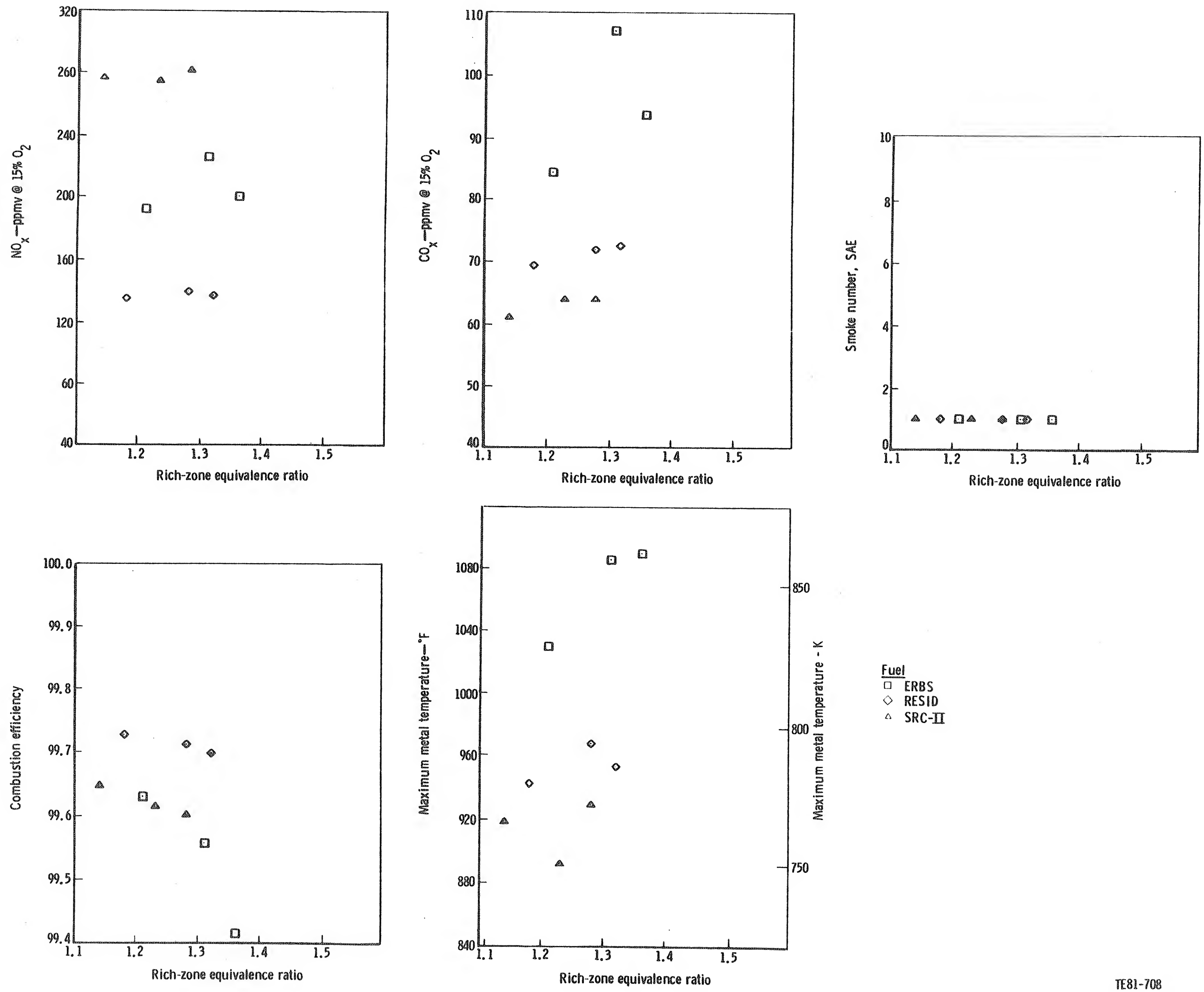

Figure 55. - RQL combustor performance at idle power.

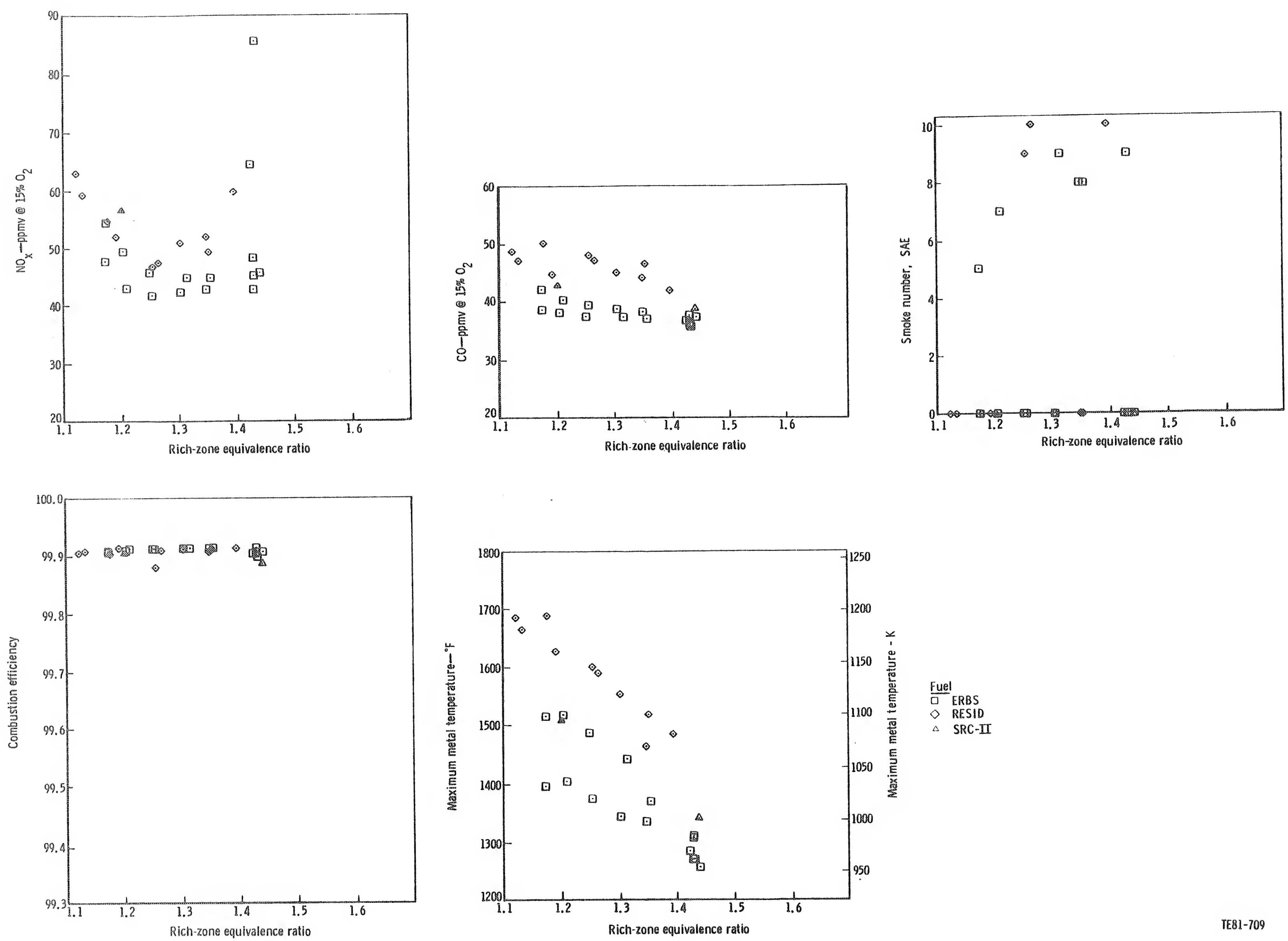

Figure 56. - RQL combustor performance at 50% load power.

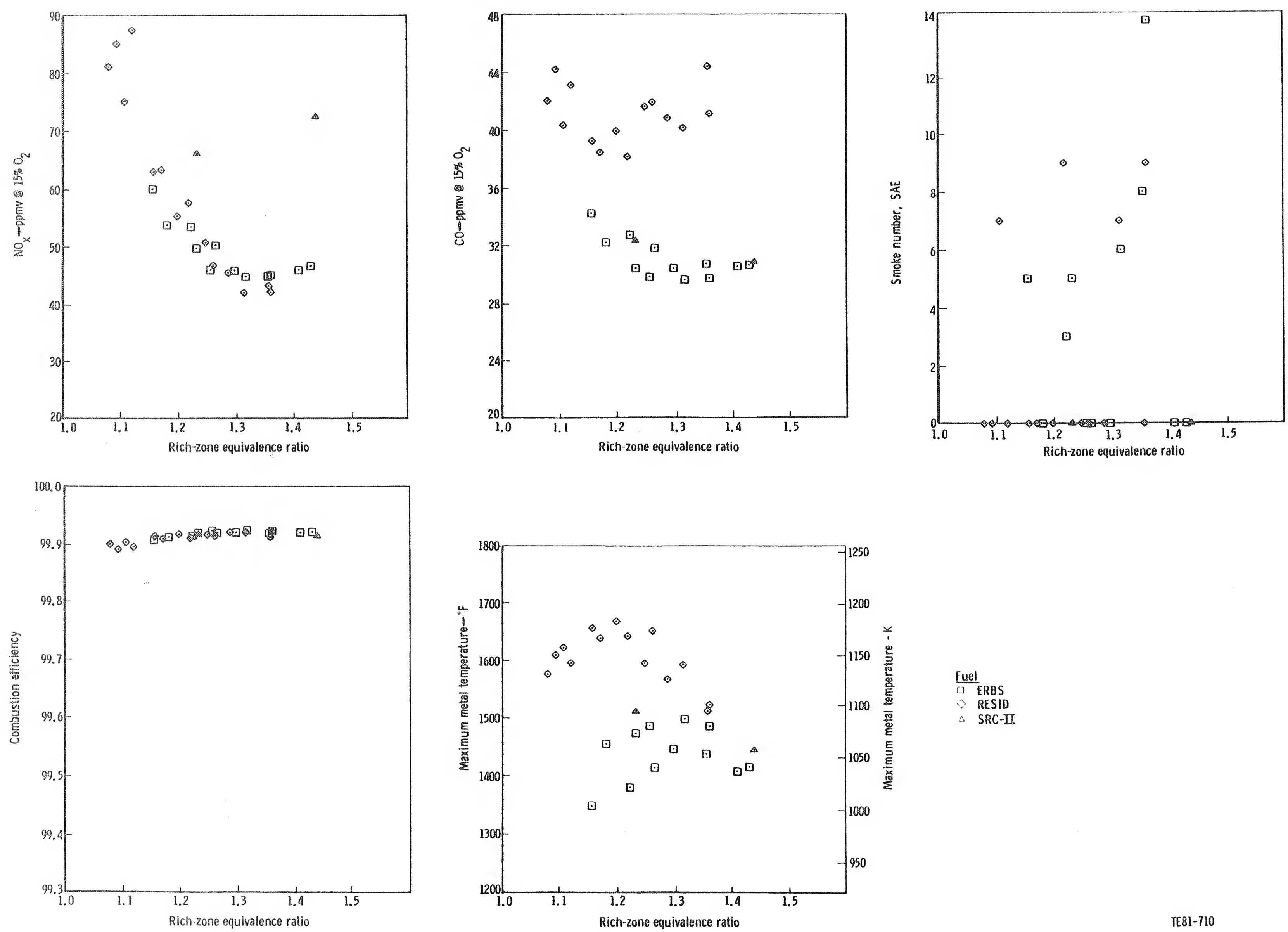

Figure 57. - RQL combustor performance at 70% load power.

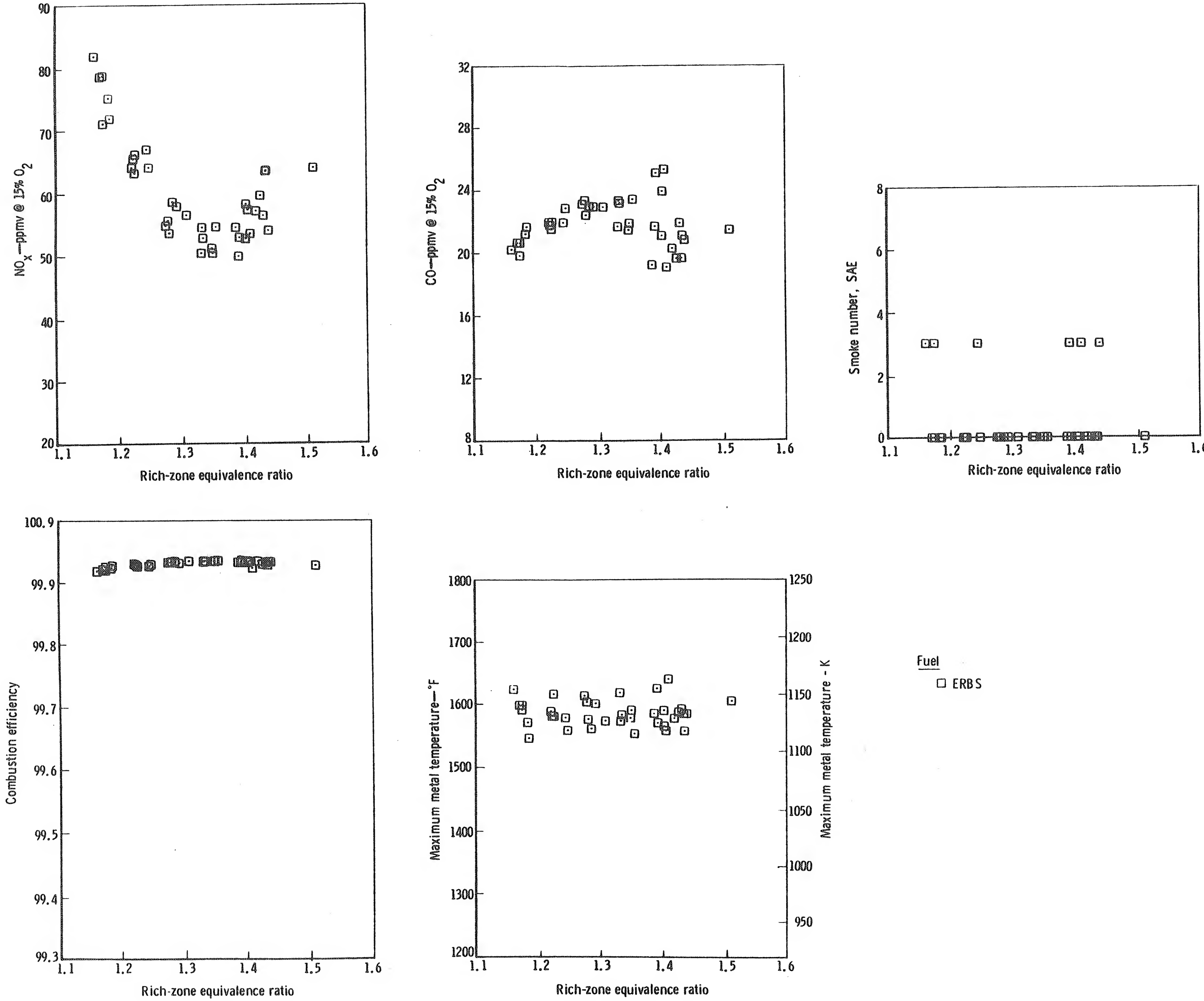

Figure 58. - RQL combustor performance at max continuous power--ERBS fuel.

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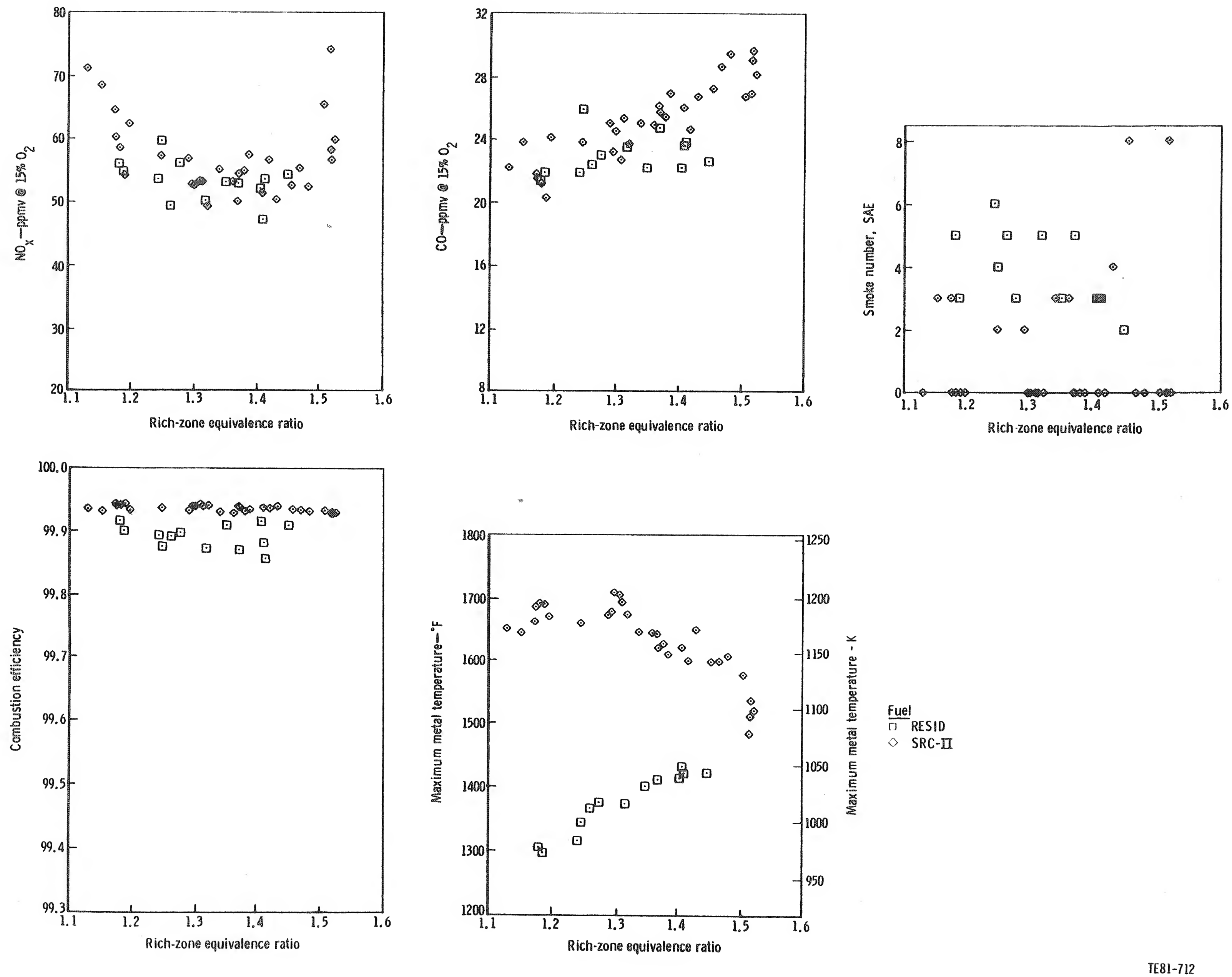

Figure 59. - RQL combustor performance at max continuous power--RESIDUAL and SRC-II fuel.

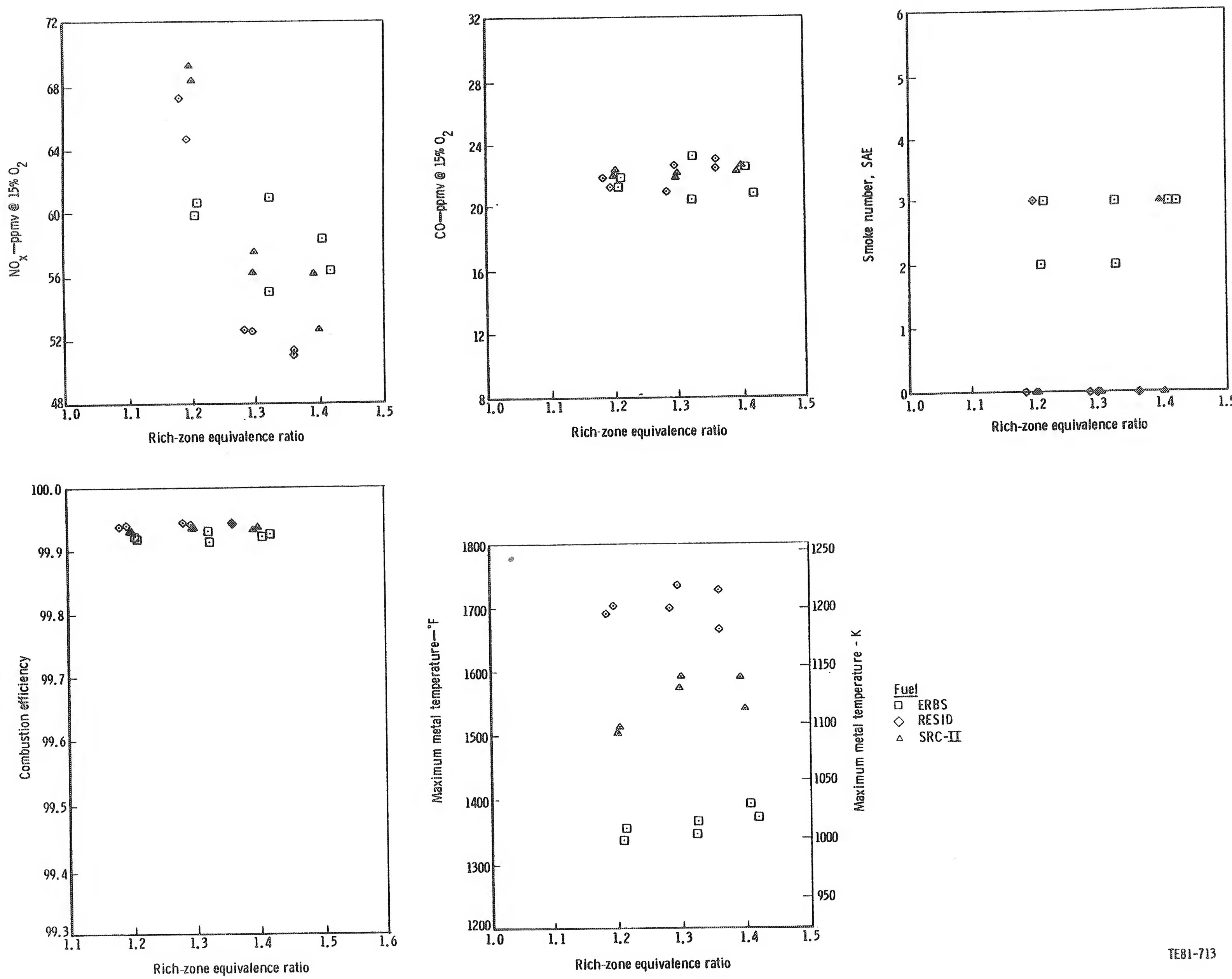

Figure 60. - RQL combustor performance at max rated power.

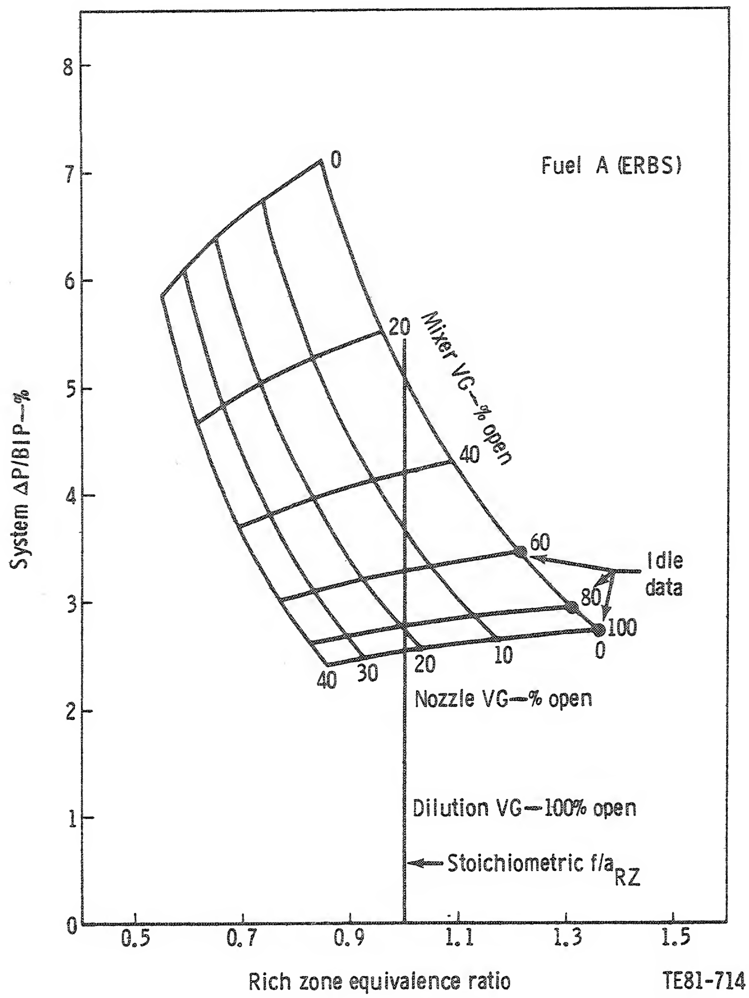

Figure 61. - Predicted variable geometry flow map for Model 570-K idle.

20 smoke number and usually below 10. Combustion efficiencies were of the order of 99.9% and above. Combustor metal temperatures consistently were highest for the RESID fuel on the order of 1200 K (1700°F) and lowest for the ERBS fuel at approximately 1090 K (1500°F).

Corrected NO_x emissions illustrate quite low levels for all three fuels. A comparison of NO_x emissions at each power level is shown in Figure 62 for ERBS fuel. The NO_x values generally increase with increasing power condi-

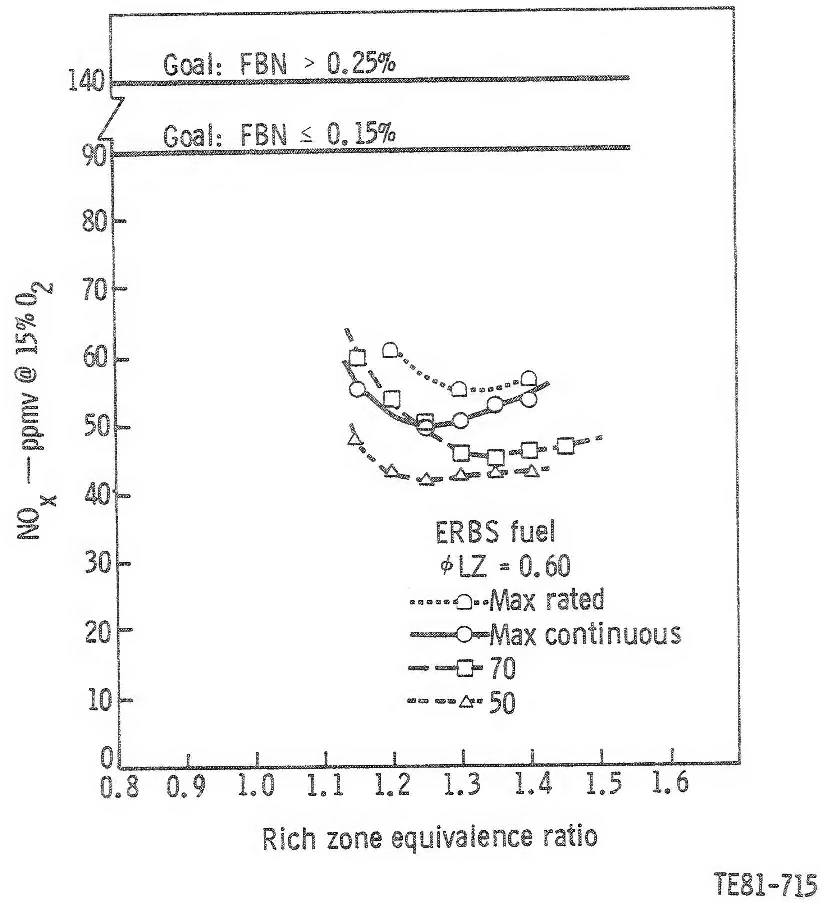

Figure 62. - NO_x response to power level.

tions and the minimum NO_x levels usually occur between 1.2 and 1.45 rich zone equivalence ratio. These data are significantly below the NO_x goal of 90 ppm for ERBS.

It must be remembered that this is a variable geometry combustor system that operated at fixed inlet conditions (airflow and fuel flow rates, temperature, and pressure). The rich-zone and lean-zone equivalence ratios were set independently with the variable-area systems of the nozzle and the mixer. The dilution zone was usually adjusted a small amount to maintain pressure drop. Over the power range from 50% load to maximum rated power, the nozzle areas were varied from full closed to 77% open, the mixer varied between 0 and 30% open, and the dilution geometry varied from 35 to 79% open. As a consequence of these ranges in flow areas, all at a constant 6% pressure drop, each data point represents a different combustor configuration. In addition to magnitudes of the air distributions, the aerodynamic performance at each air entry

changed with the setting. This was especially true of the fuel nozzle and the mixer. At low airflow configurations (nearly closed) the fuel nozzle generated a solid-cone fuel spray having large droplets with a tight recirculation loop against the diverging dome surface of the rich zone. As the nozzle area was opened, the spray transferred to a hollow cone and the droplet sizes decreased substantially. The recirculation loop lengthened out to encompass the front half of the rich zone. The mixer's variable geometry made similar changes to the quick quenching aerodynamics with the rich-zone products. Accompanying the changes in airflow injected through the mixer, were changes in hole shape as the slot open areas translated from triangular holes to slots and from one row of slots to two rows. Therefore the results are felt to be unique to this RQL combustor, and although the results are only correlated to rich-zone equivalence ratio, other parameters are simultaneously varying.

A plot of minimum NO_x over the power range for each fuel is shown in Figure 63. In general, the minimum NO_x level increases as output shaft power is increased. Only two data points were recorded for SRC-II fuel at 50 and 70% load; thus, no minimum was defined for those two conditions.

A considerable amount of data was recorded at maximum continuous power. A comparison of NO_x emissions for all three fuels is shown in Figure 64. All three fuels displayed minimum NO_x of approximately the same magnitude within a rich zone equivalence ratio range of 1.3 to 1.45.

Figure 64 also shows that minimum NO_x was insensitive to the FBN inherent in the RESID and the SRC-II fuels. Depicted somewhat differently in Figure 65, the minimum NO_x is almost the same for all three fuels. At rich zone equivalence ratios away from the minimum, the NO_x emission levels began to vary significantly. This is shown more clearly in Figures 66 through 68, which show NO_x variations for differing amounts of 2-vinylpyridine addition. The minimum NO_x level remained near the 1.3 rich-zone equivalence ratio and was relatively insensitive to increases in FBN. However, as one moves away from the minimum NO_x the effect of pyridine additions is different. As equivalence ratio is reduced from the value at minimum NO_x, increasing FBN lowers the NO_x emissions. Then as equivalence ratios are increased to richer values than at minimum NO_x, the pyridine FBN increases NO_x.

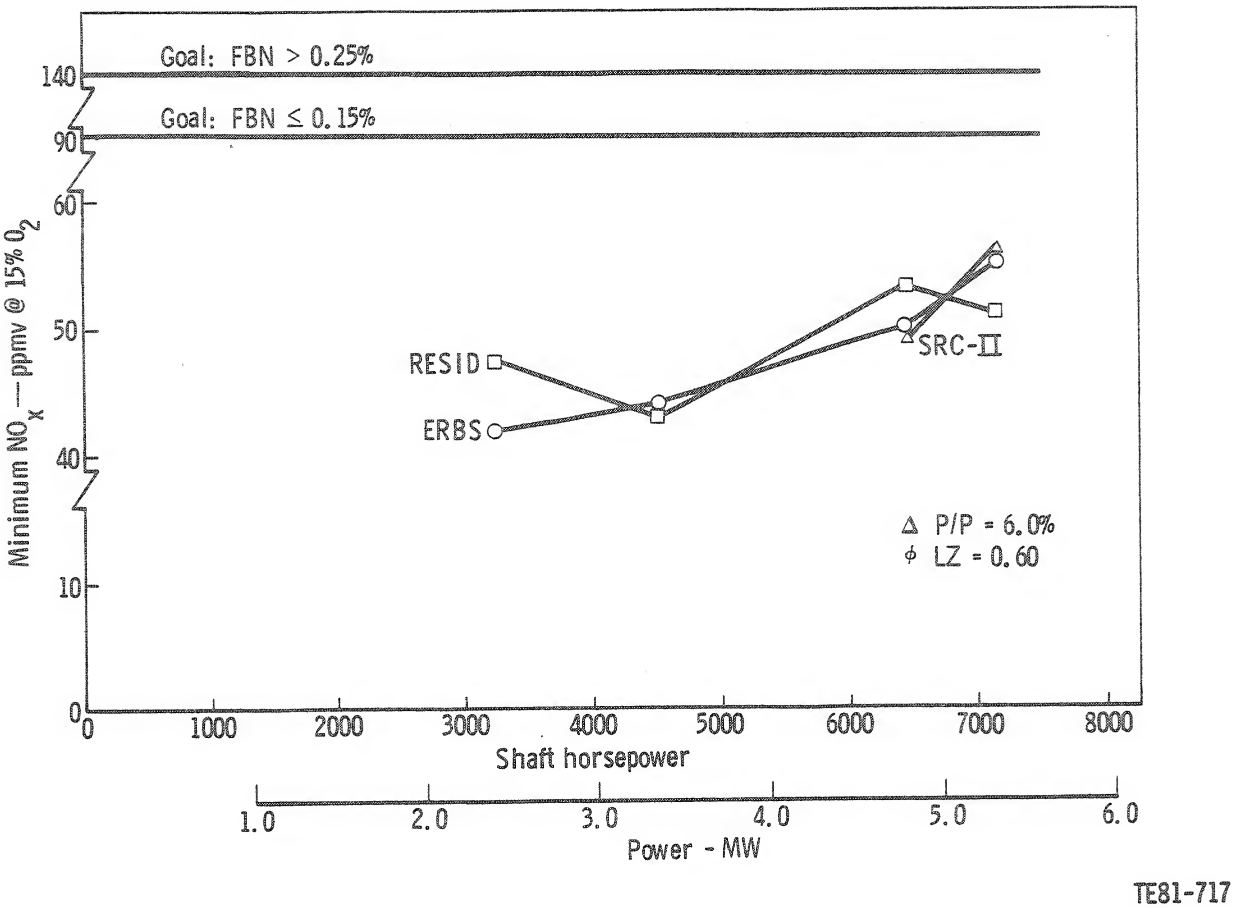

Figure 63. - Minimum NO_x response to power level.

This phenomenon was observed for both the RESID and the SRC-II fuels. The only pyridine addition to ERBS fuel during the performance testing was at 50% load power (see Figure 69). At this point the rich zone equivalence ratio was 1.4 and the lean zone 0.60. This condition is a rich zone equivalence ratio somewhat higher than the minimum NO_x value for this fuel, and thus adding pyridine FBN increased NO_x emissions.

Parametric Testing

After performance testing the RQL combustor over the engine operating range using all three fuels, a series of parametric tests was defined to evaluate the sensitivity of the RQL combustor to a variety of operating parameters. There were three parameters investigated: lean zone equivalence ratio, system pressure drop, and system residence time. ERBS and RESID fuels were used and the effects of FBN were investigated by adding varying amounts of 2-vinyl-pyridine (C_7H_7N).

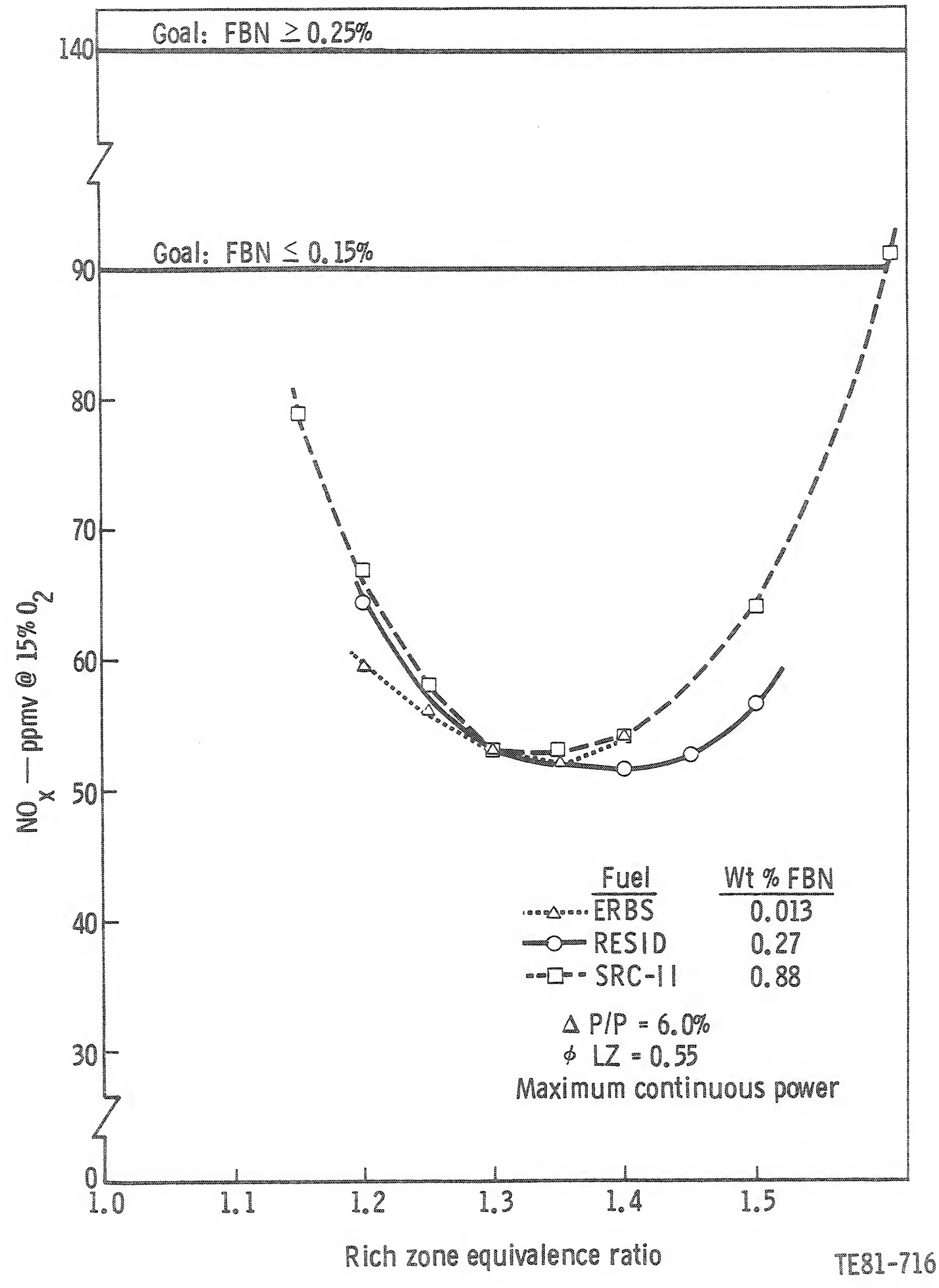

Figure 64. - NO_x response to base fuel FBN content.

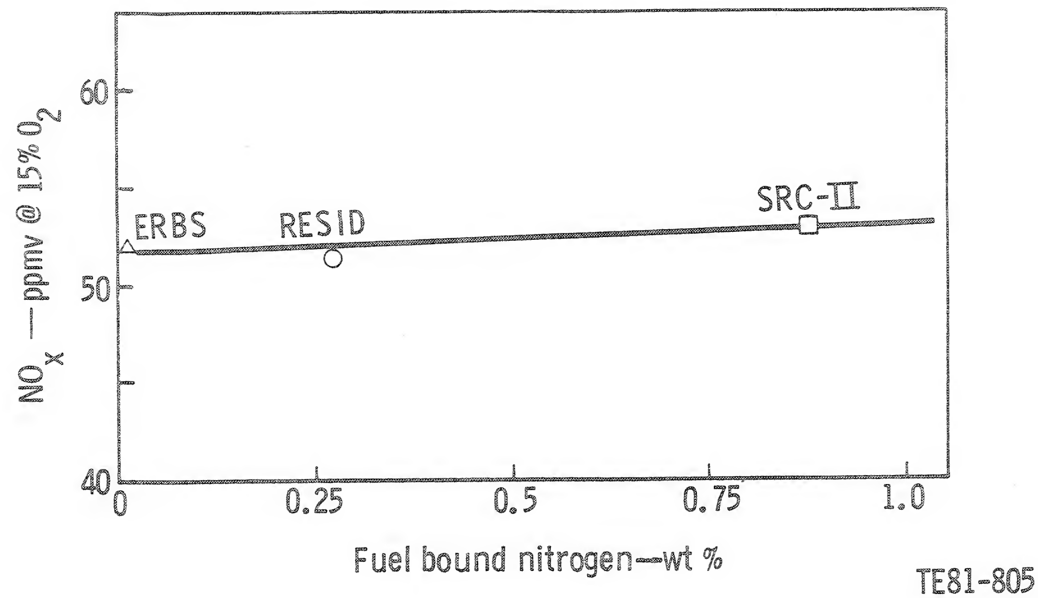

Figure 65. - Minimum NO_x vs fuel bound nitrogen of the base fuels.

The majority of the parametric testing was done with the ERBS fuel. Each plot in this section is NO_x emissions in ppm by volume corrected to 15% oxygen. The NO_x was plotted against the abscissa parameter rich-zone equivalence ratio. The parametrics on ERBS fuel will be presented first, then the RESID fuel results.

The ERBS and RESID fuel parametrics were run for rich zone fuel-air ratios of 1.2 to 1.5 since for the performance testing the minimum NO_x had resulted in the 1.3 to 1.45 range. The coal-derived SRC-II fuel was not used in this series of tests because the ERBS (a low FBN fuel) and RESID (a high FBN fuel, FBN $\geq$ 0.25) covered the range in FBN specified in the EPA emissions regulations and together gave the widest diversity in overall properties. Throughout the test series degradation in hardware occurred due to durability and wear of variable geometry components, thus affecting accurate setting of zone flow splits.

ERBS Fuel

The first parametric conducted on ERBS fuel was the variation in lean zone equivalence ratio. The lean zone equivalence ratio variation was 0.50 to 0.65. Figure 70 shows NO_x for four different lean-zone equivalence ratios

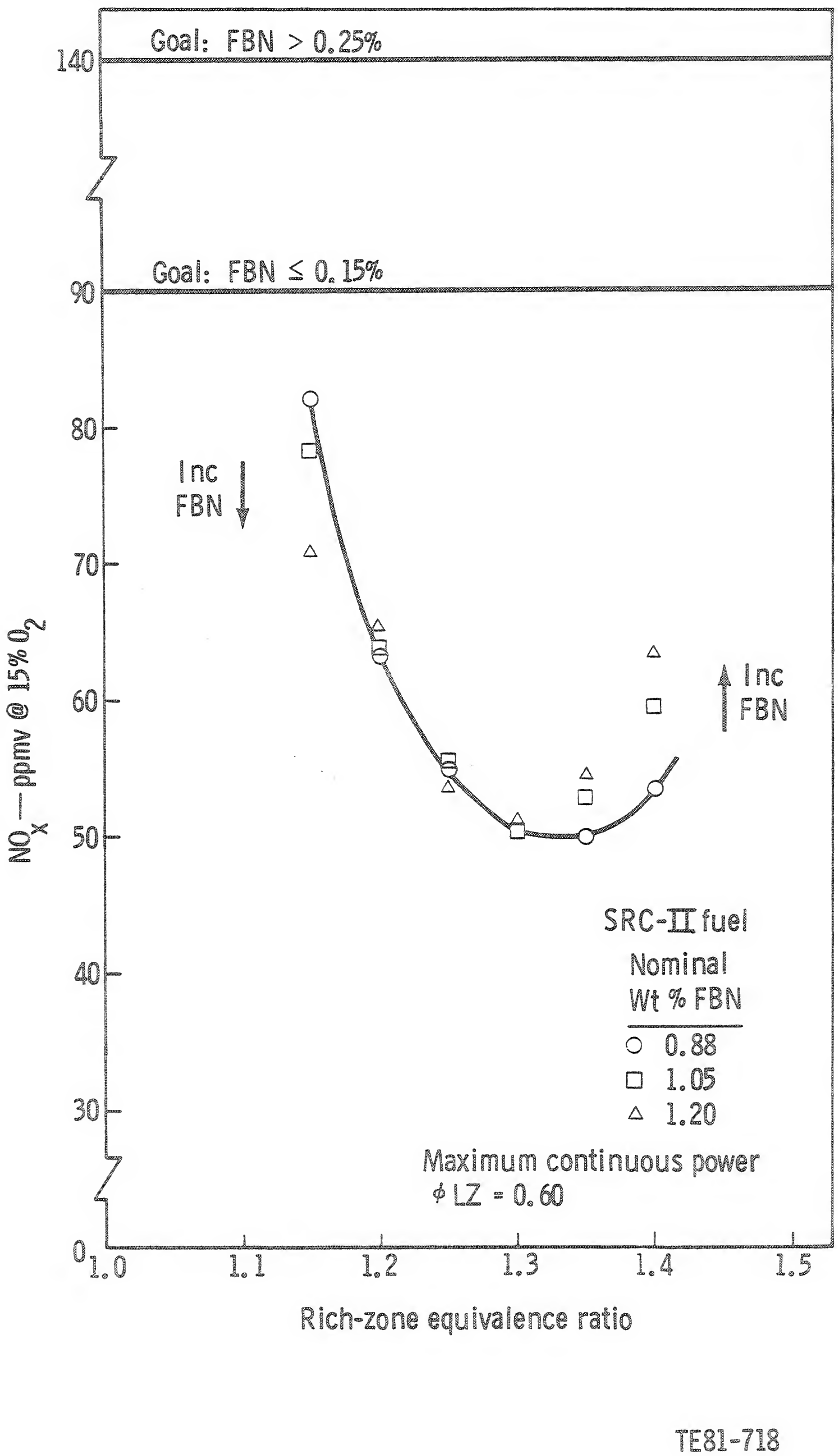

Figure 66. - NO_x response to FBN content SRC-II fuel.

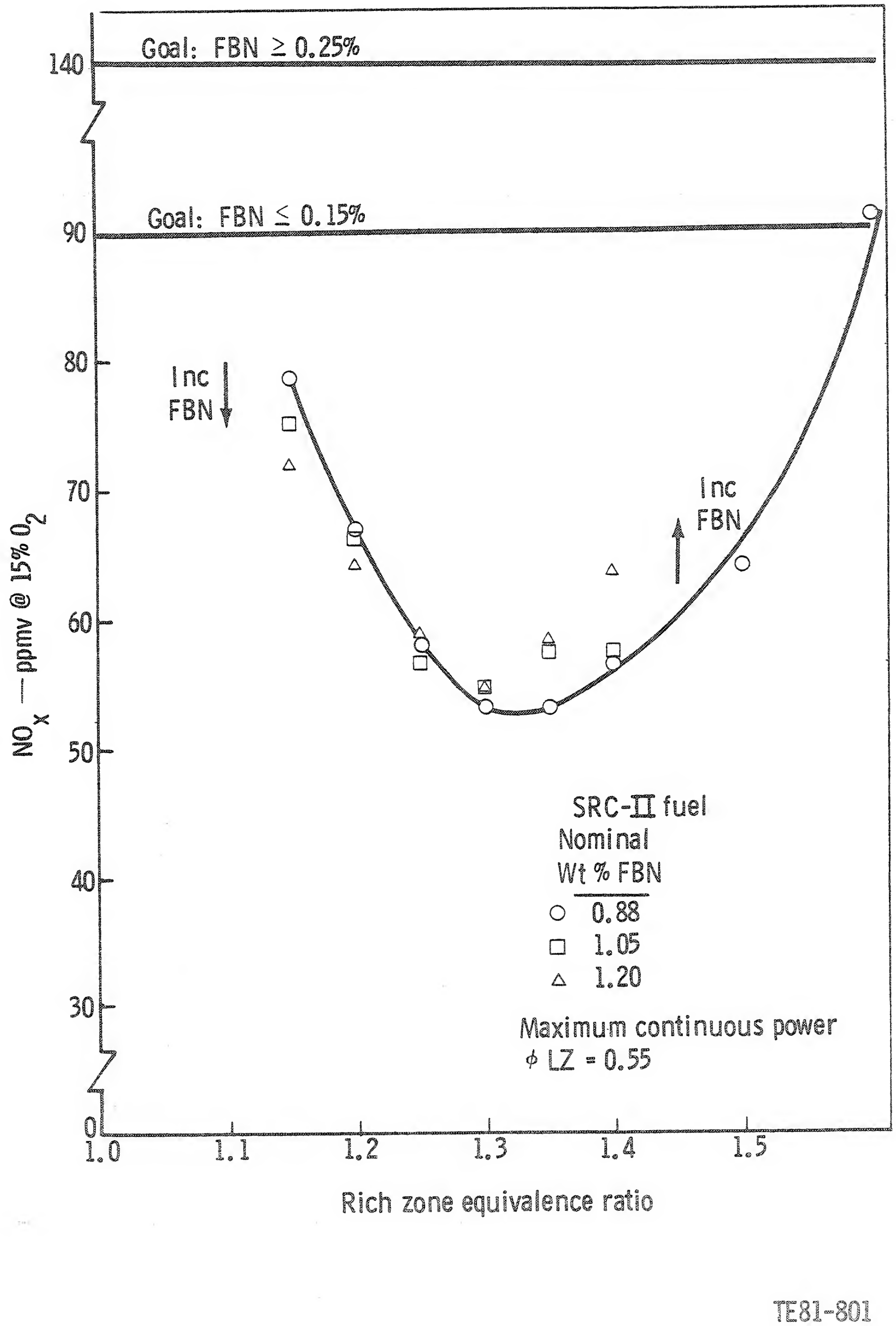

Figure 67. - NO_x response to FBN content SRC-II fuel.

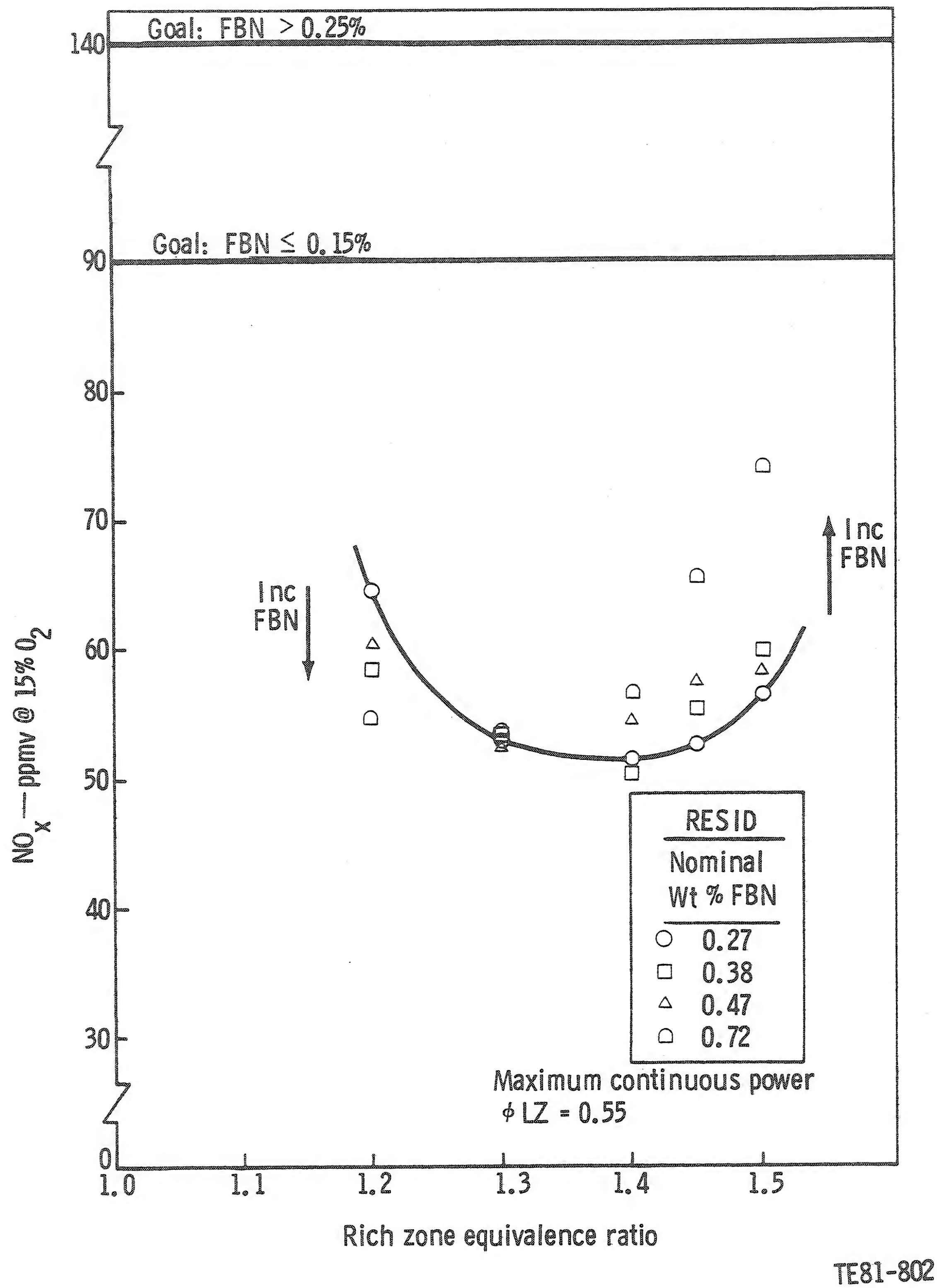

Figure 68. - NO_x response to FBN content RESID fuel.

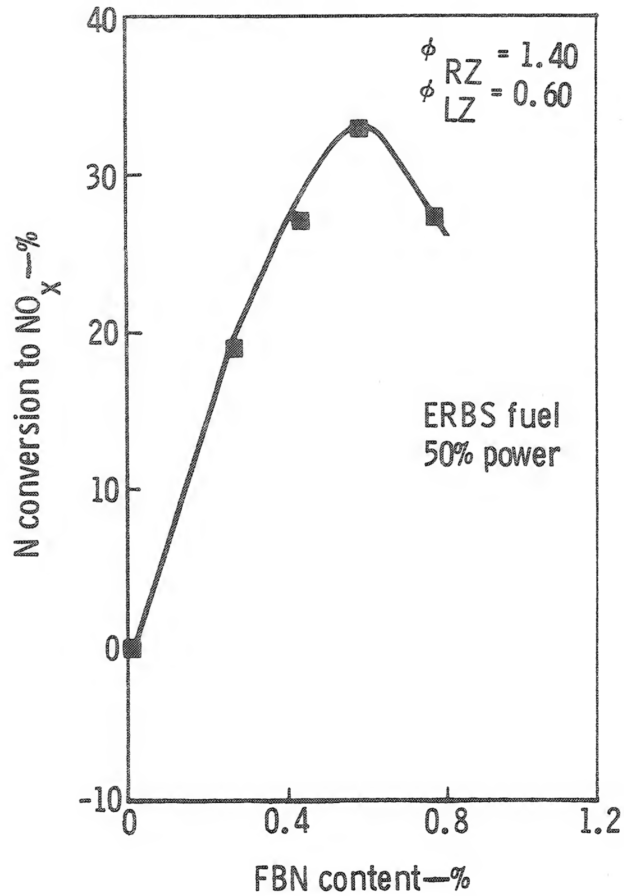

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Figure 69. - N conversion to NO_x at 50% power--ERBS fuel.

having lines of constant FBN. In Figure 71 the same data are shown as plots of constant FBN having lines of lean zone equivalence ratio. Fuel bound nitrogen levels run were 0.013 (ERBS only), 0.38, 0.55, and 0.72% by weight. Most of the data taken were on the lean side of the minimum NO_x point; thus, minimum NO_x could not be defined. Contrary to the performance testing at max continuous power with RESID and SRC-II fuels, pyridine addition on the lean side of minimum NO_x resulted in NO_x increases. Variation on the rich side of minimum NO_x was not obtained. Unburned hydrocarbon emissions, carbon monoxide emissions, and smoke remained at the low levels recorded in the performance testing with no discernible trends evident.

A set of data points documenting the effect on NO_x of system pressure drop, i.e., mixing, was taken next. The pressure drop variation was 6, 5, and 4%, the lean zone equivalence ratios were 0.50 and 0.60, and the FBN variation was

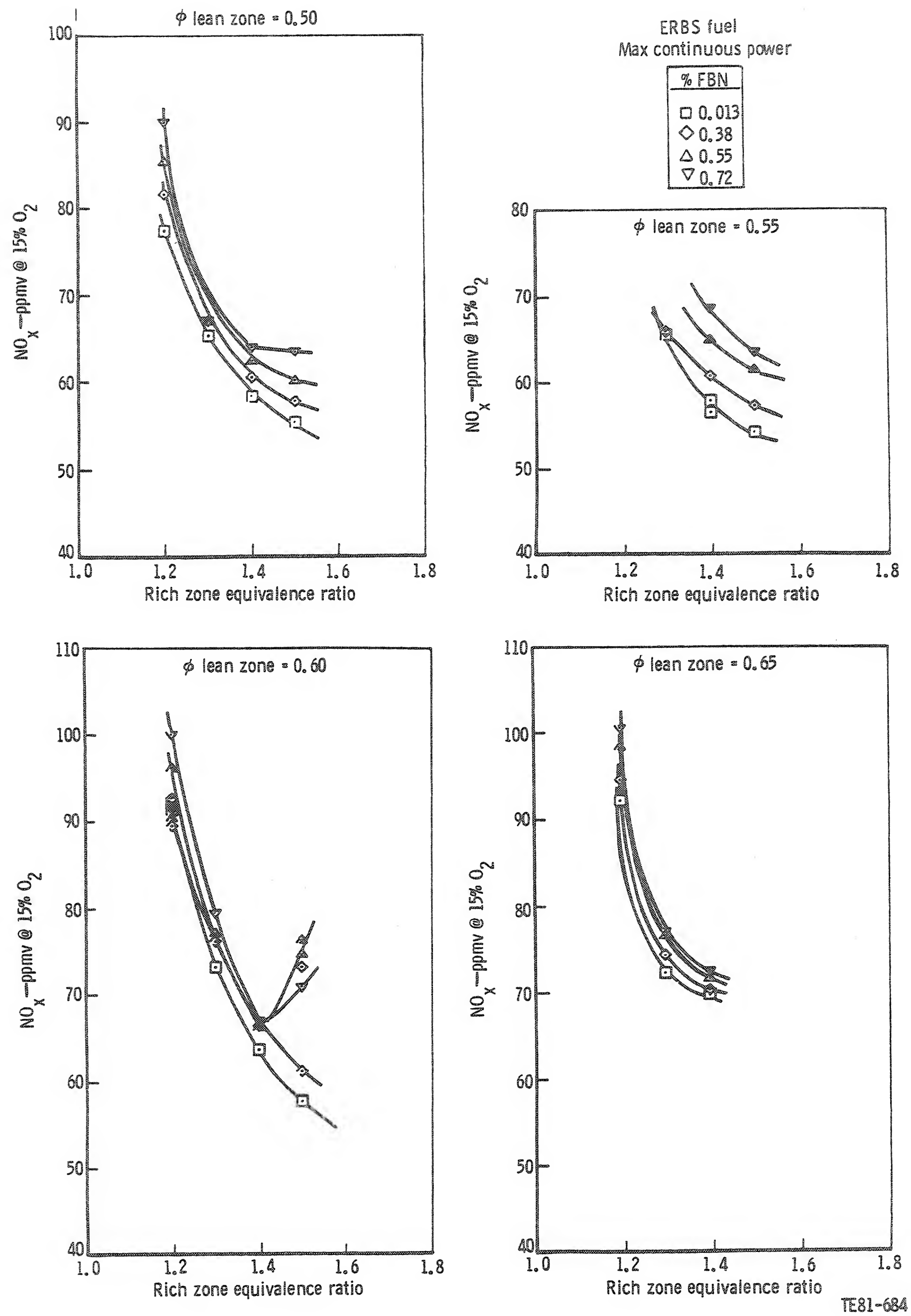

Figure 70. - Lean-zone equivalence ratio parametric study--lean zone equivalence ratio variation.

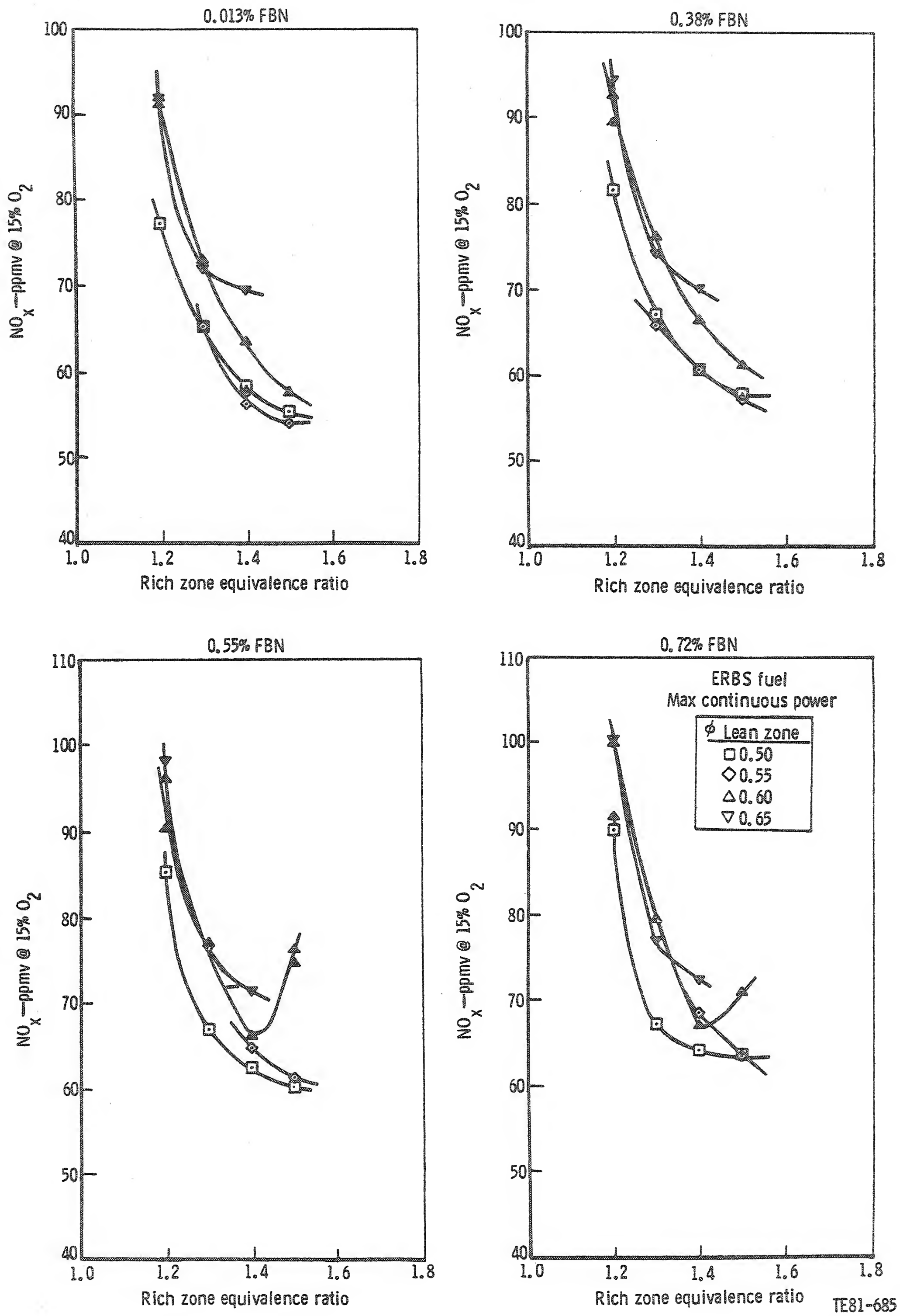

Figure 71. - Lean-zone equivalence ratio parametric study--FBN variation.

from 0.013 to 0.72% by weight. Plots of these data are shown in Figures 72 through 75. Rich zone equivalence ratios again ranged from 1.2 to 1.5. The data indicate that the minimum NO_x equivalence ratio points moved inversely with pressure drop. It must be remembered that all of these data were taken at constant inlet conditions (air mass flow, pressure, temperature, and fuel flow). As pressure drop decreased, the variable geometry systems were each opened to rebalance the internal flow distribution. Thus, in addition to orifice sizes changing, the shapes are also changing.

The final ERBS fuel parametric was an investigation of residence time. Residence time was reduced by increasing air and fuel flows, keeping the overall fuel-air ratio the same. For these data points the variable geometry systems were each adjusted so that the 6% pressure drop was maintained at each increase in fuel and air. The residence time plots are presented in Figures 76 through 79 for three relative residence times, two lean-zone equivalence ratios, and four levels of FBN. As with the pressure drop data, the rich-zone equivalence ratio for minimum NO_x varies with residence time, becoming more fuel lean with decreasing residence time. Rich zone residence time, based on combustor inlet conditions at maximum continuous power and a 1.35 rich zone equivalence ratio, is 74.0 ms. Therefore, at the higher flows the residence times would be 64.3 and 56.9 ms.

RESID Fuel

The balance of the parametric testing was conducted with the RESID fuel. Figures 80 and 81 show NO_x emissions for three levels of pressure drop: 6, 5, and 4%. The RESID fuel NO_x data show the same characteristic as the ERBS fuel NO_x data. The minimum NO_x point moves to leaner rich-zone equivalence ratios and the minimum NO_x level increases as pressure drop is reduced. With the addition of two-vinyl pyridine, the rate of NO_x conversion from FBN appears to decrease, as does the absolute level of the NO_x emissions. The FBN content of the RESID fuel is 0.27% by weight so that the FBN content inherent in the fuel may influence the FBN conversion chemistry in the rich zone.

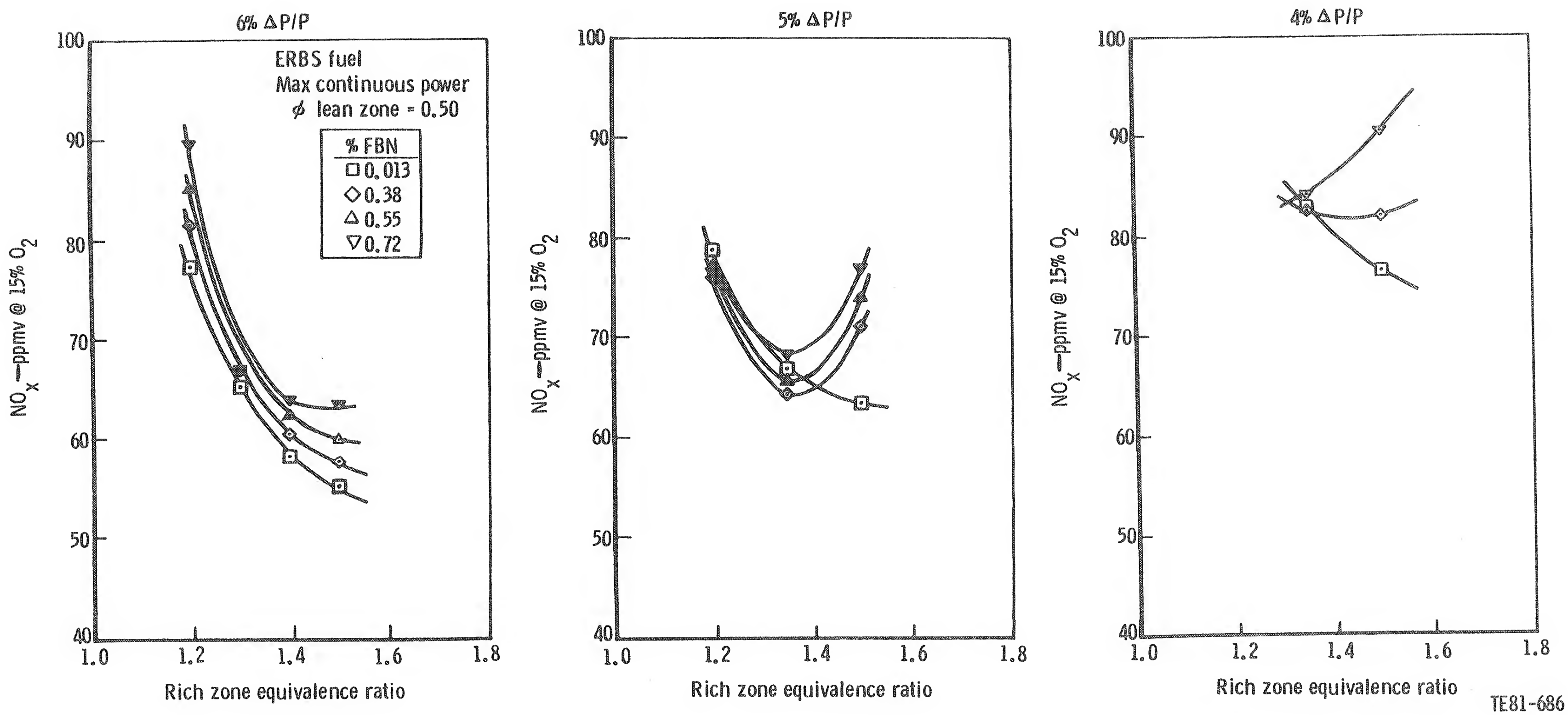

Figure 72. - Pressure drop parametric study--pressure drop variation.

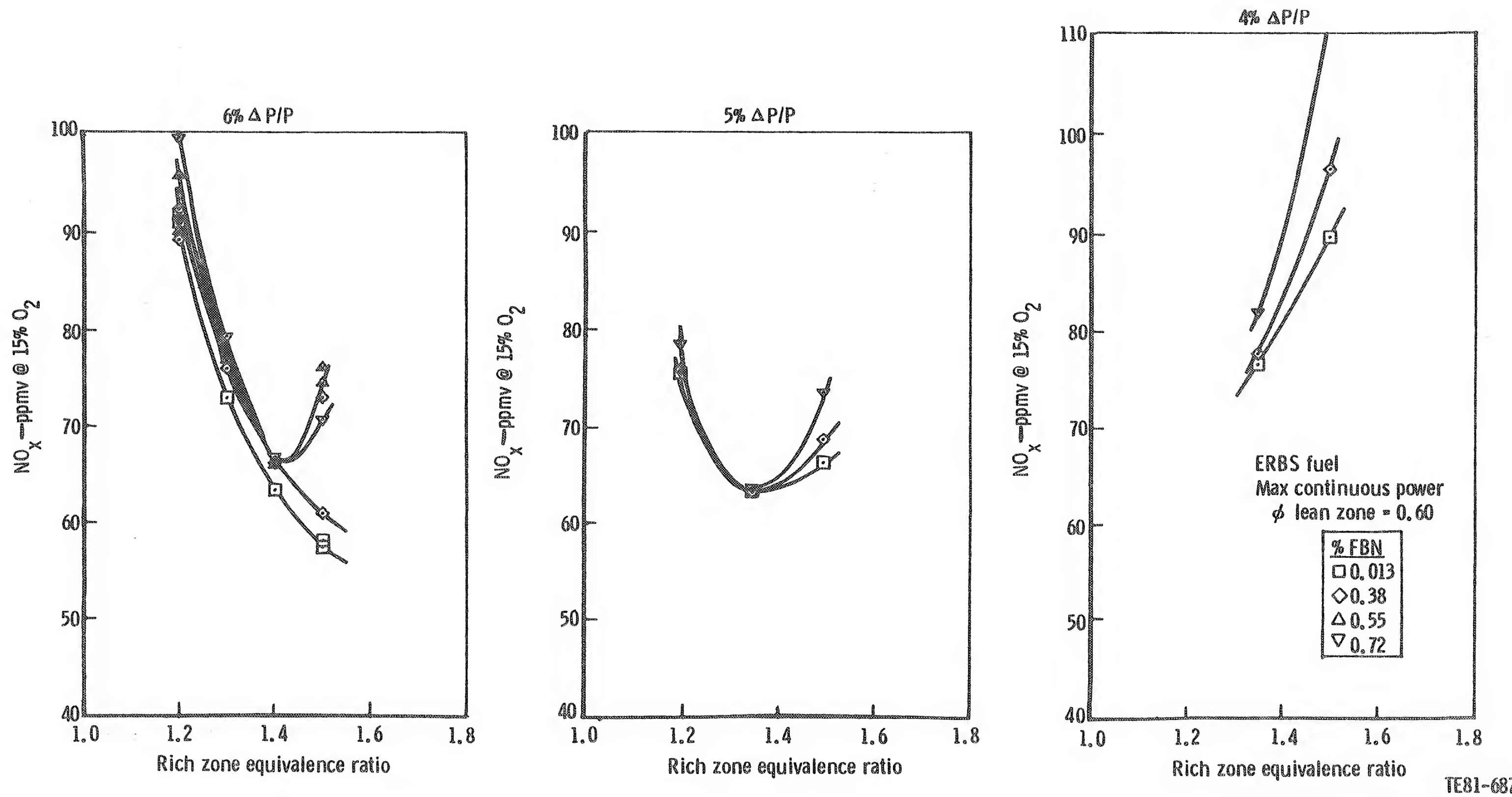

Figure 73. - Pressure drop parametric study--pressure drop variation.

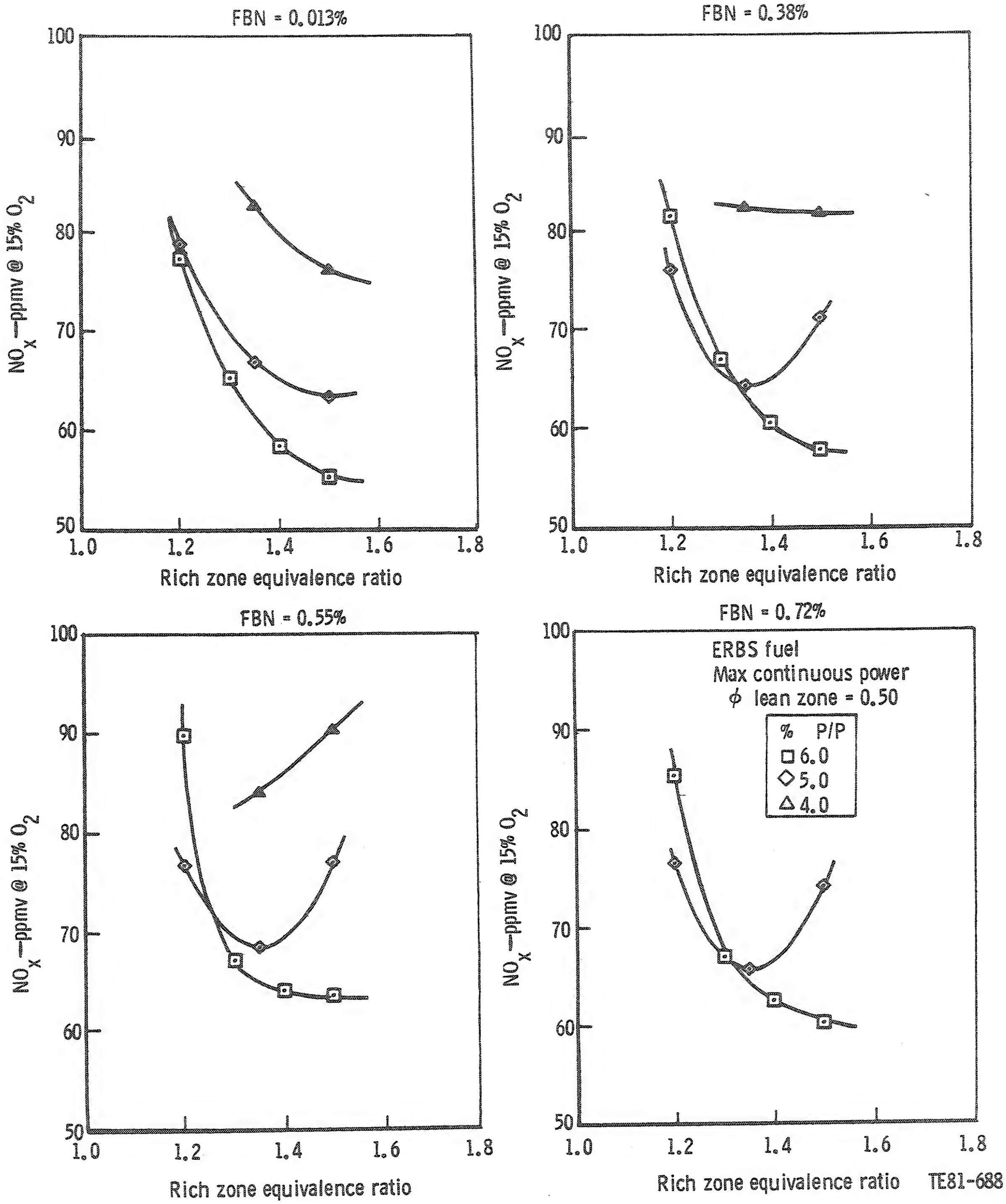

Figure 74. - Pressure drop parametric study--FBN variation.

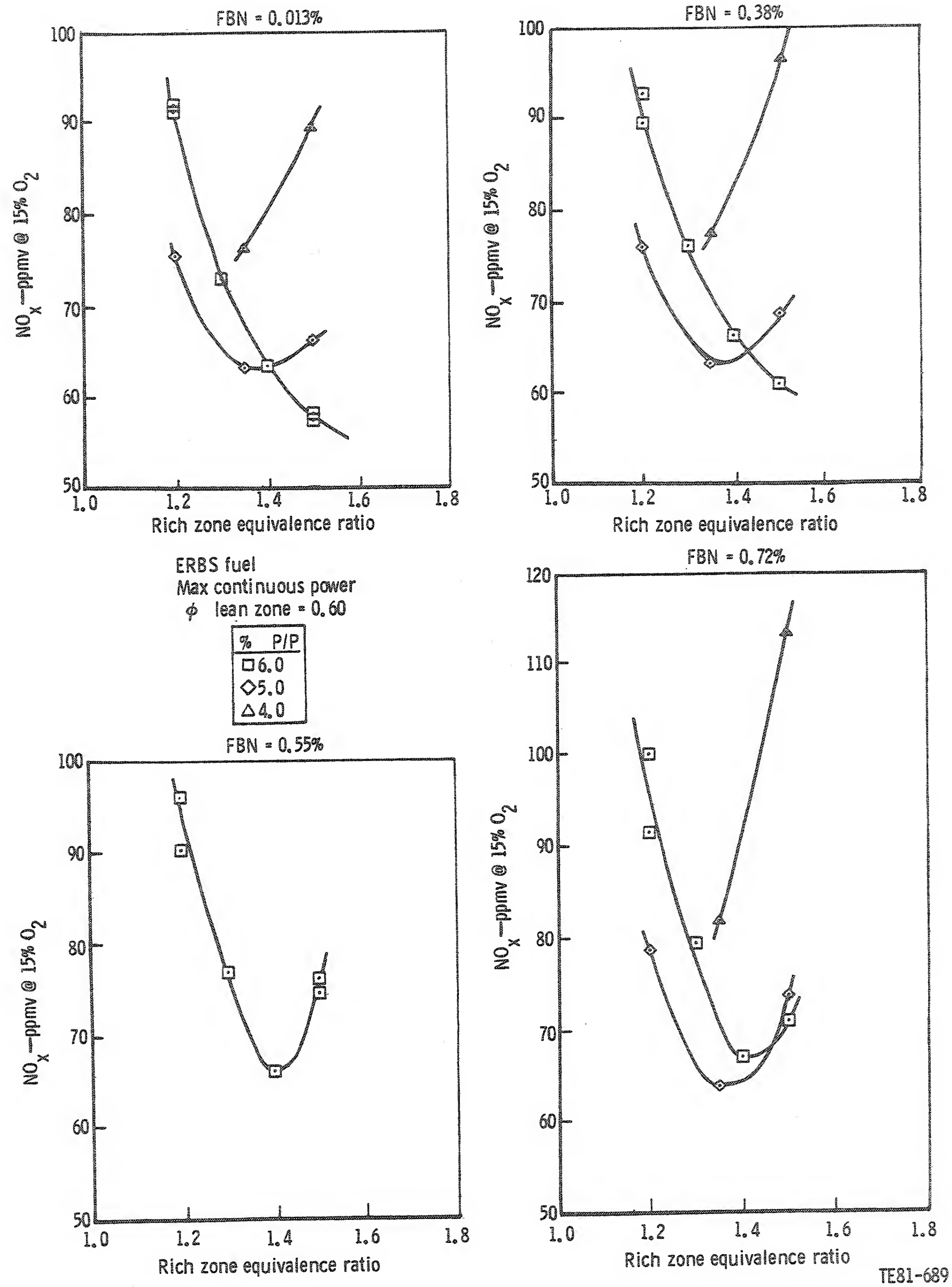

Figure 75. - Pressure drop parametric study--FBN variation.

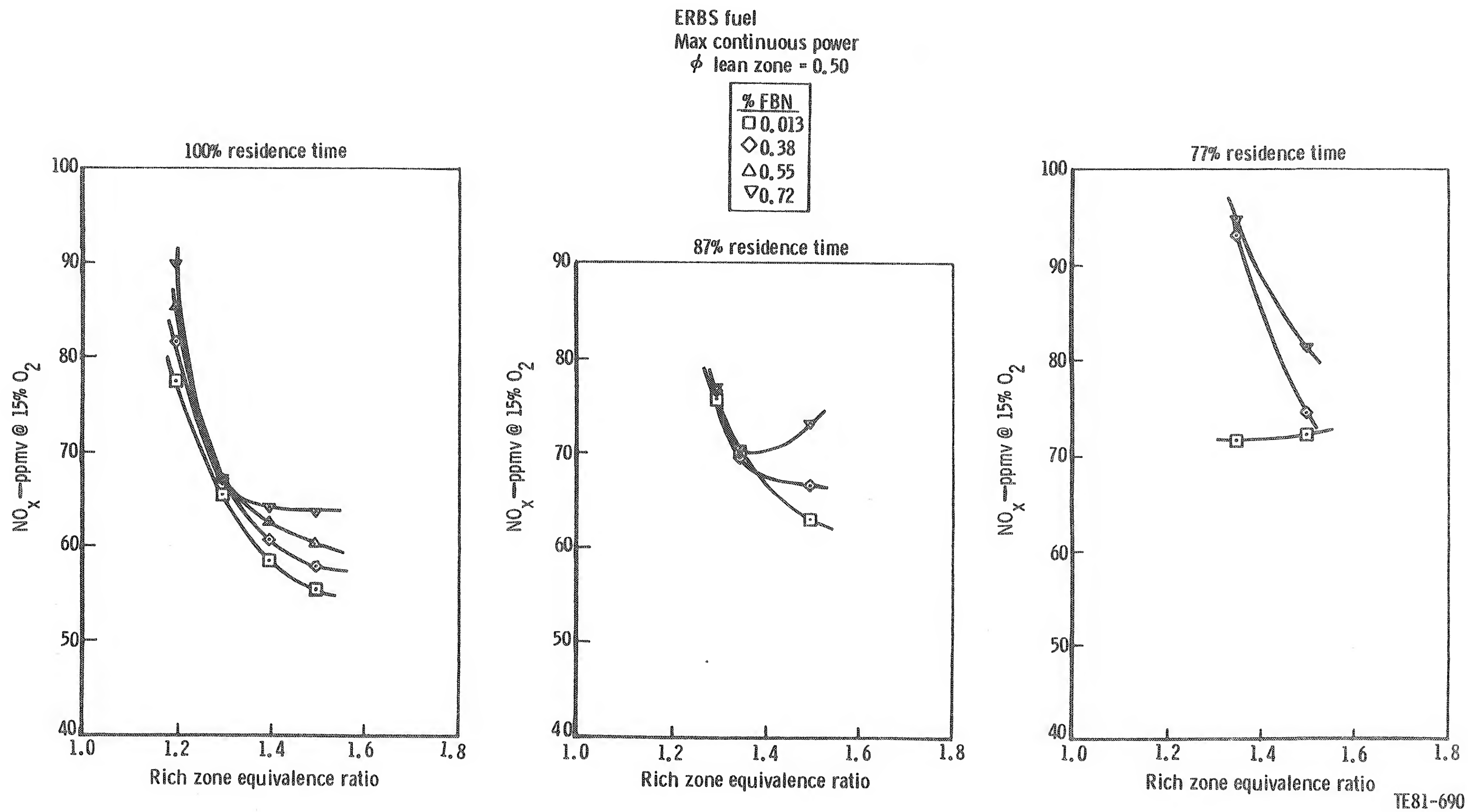

Figure 76. - Residence time parametric study--residence time variation.

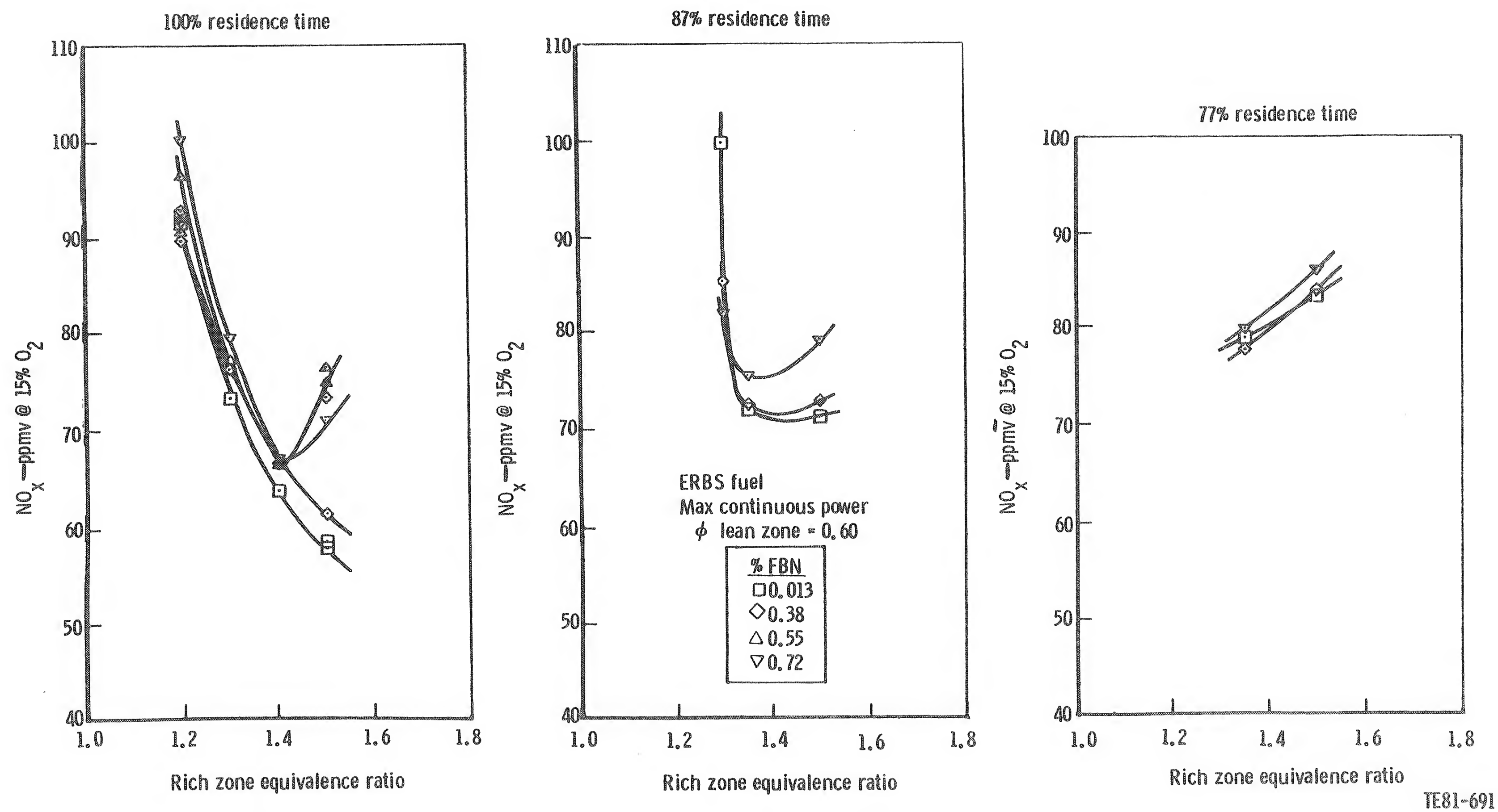

Figure 77. - Residence time parametric study--residence time variation.

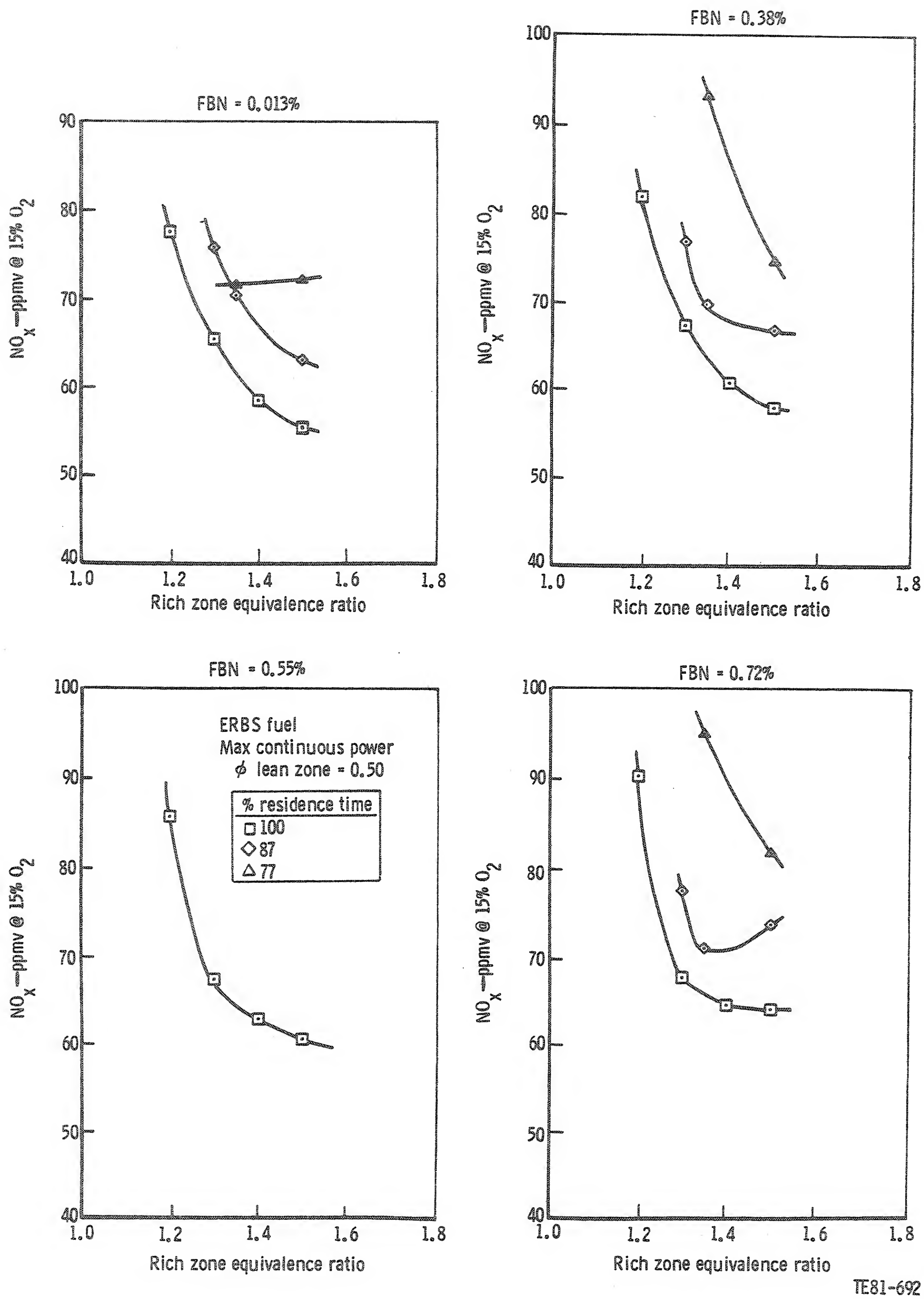

Figure 78. - Residence time parametric study--FBN variation.

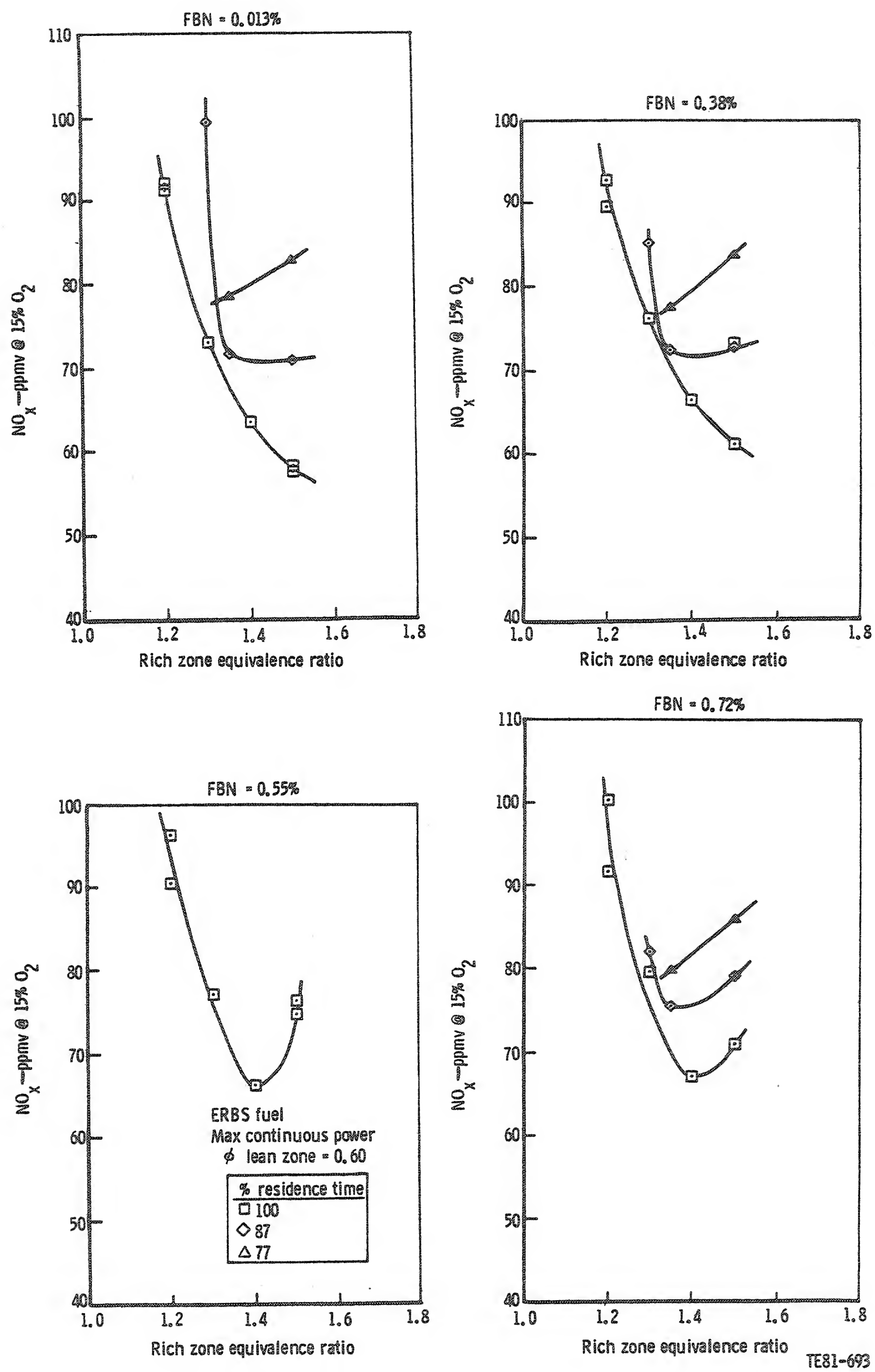

Figure 79. - Residence time parametric study--FBN variation.

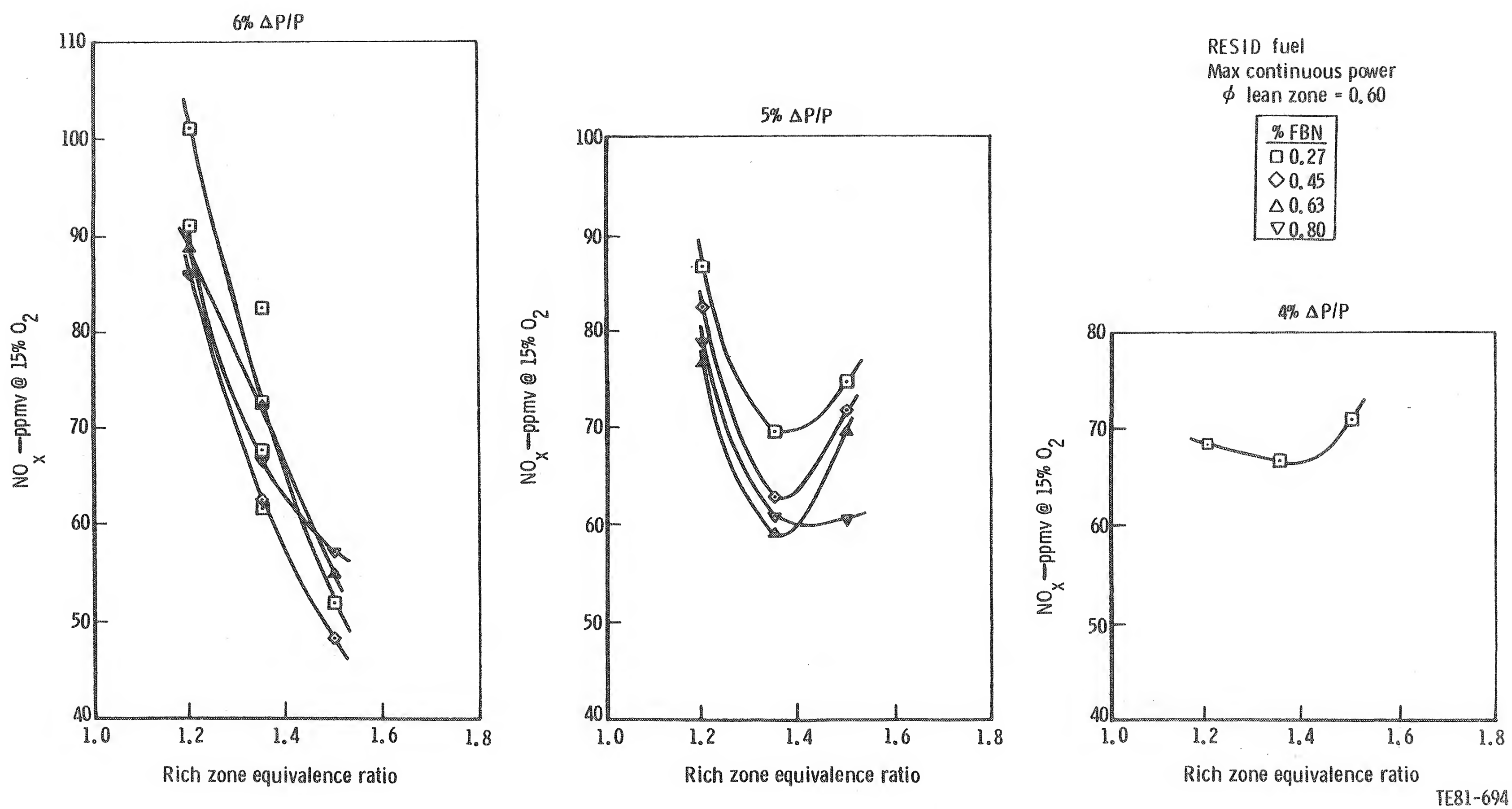

Figure 80. - Pressure drop parametric study--pressure drop variation.

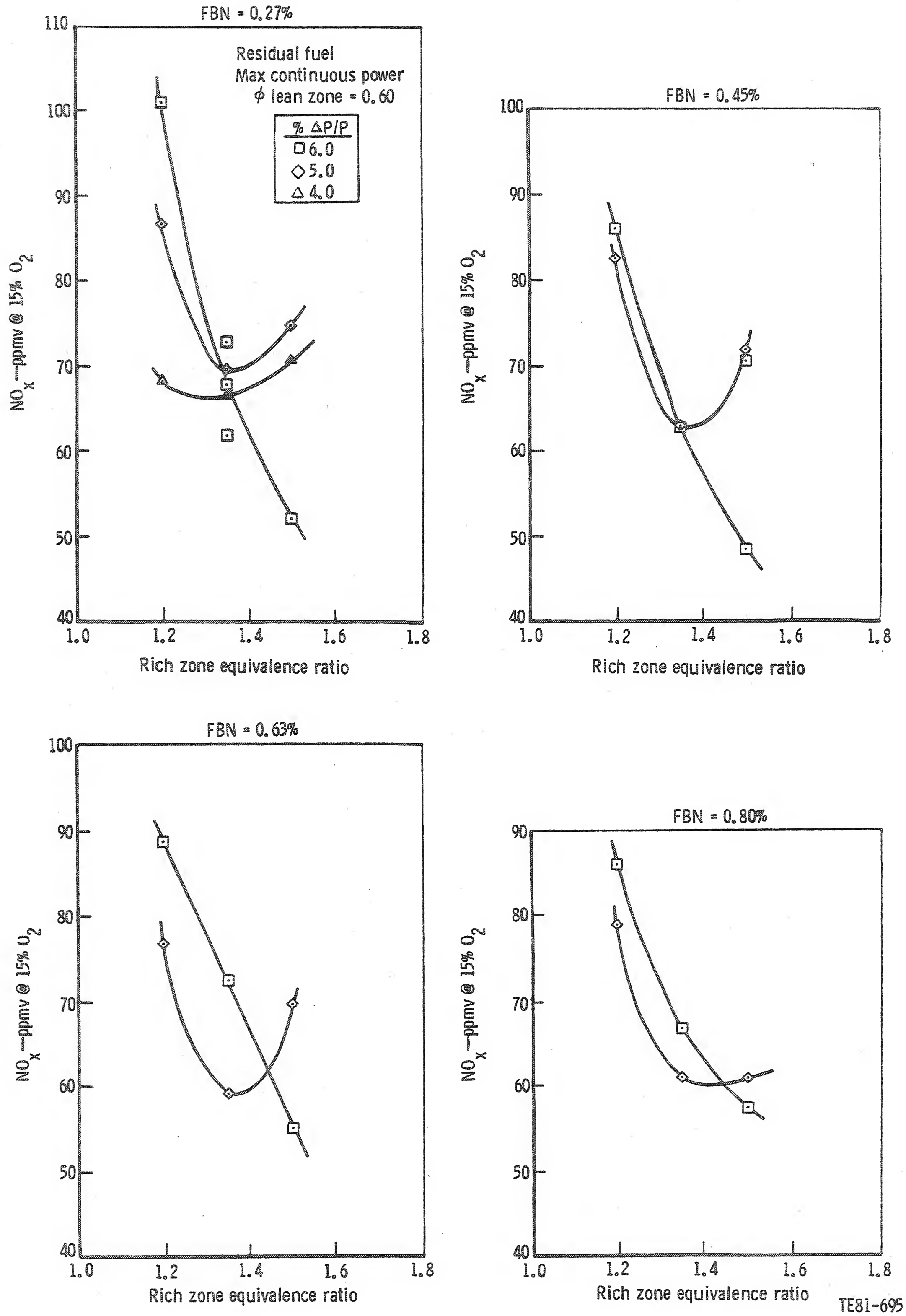

Figure 81. - Pressure drop parametric study--FBN variation.

The residence time RESID fuel parametric results are shown in Figures 82 and 83. Here again the reduced residence times shifted the minimum NO_x points to more lean rich-zone equivalence ratios as residence time was reduced. The minimum NO_x level appears to increase as residence time is reduced. For the limited data at 0.50 and 0.60 lean zone equivalence ratios, the effect of lean zone equivalence ratio appeared to be of a secondary nature.

Corrected NO_x emissions are shown in Figure 84 as a function of inlet air temperature. The test point was maximum continuous power with a pressure drop of 6%, rich-zone equivalence ratio of 1.35, and a lean zone equivalence ratio of 0.60. The NO_x increased 15 ppmv for a 58 K (104°F) increase in inlet air temperature.

One additional check was made during the parametric testing: the effect of fuel temperature on NO_x. For all of the RESID fuel testing the fuel temperature entering the combustor was 395 K (250°F). Corrected NO_x at maximum continuous power conditions (6% pressure drop, 1.50 rich zone equivalence ratio, 0.60 lean zone equivalence ratio), was 66 ppmv at the normal fuel temperature [395 K (251°F)]. When the fuel temperature was reduced 28 K to 367 K (200°F), the corrected NO_x was 65 ppmv. Thus over the small fuel temperature range investigated, there was essentially no change in the NO_x level.

Variable Geometry Requirements for Engine Application

This section describes a critique of the RQL data to determine if the variable geometry features of the RQL combustor are necessary for durable, efficient and clean operation over the Model 570-K engine cycle. The RQL combustor with its three variable geometry air entry locations provided an ideal test vehicle to evaluate parametrically the performance of zone airflow distributions and pressure loss levels. Although well suited for this program, consideration must be given to the feasibility of a VG combustion system on full engine application. In evaluating a VG combustion system one must keep in mind that: design and fabrication processes usually are more complex; fabrication of VG bands and actuation equipment must be held to extremely tight tolerances,

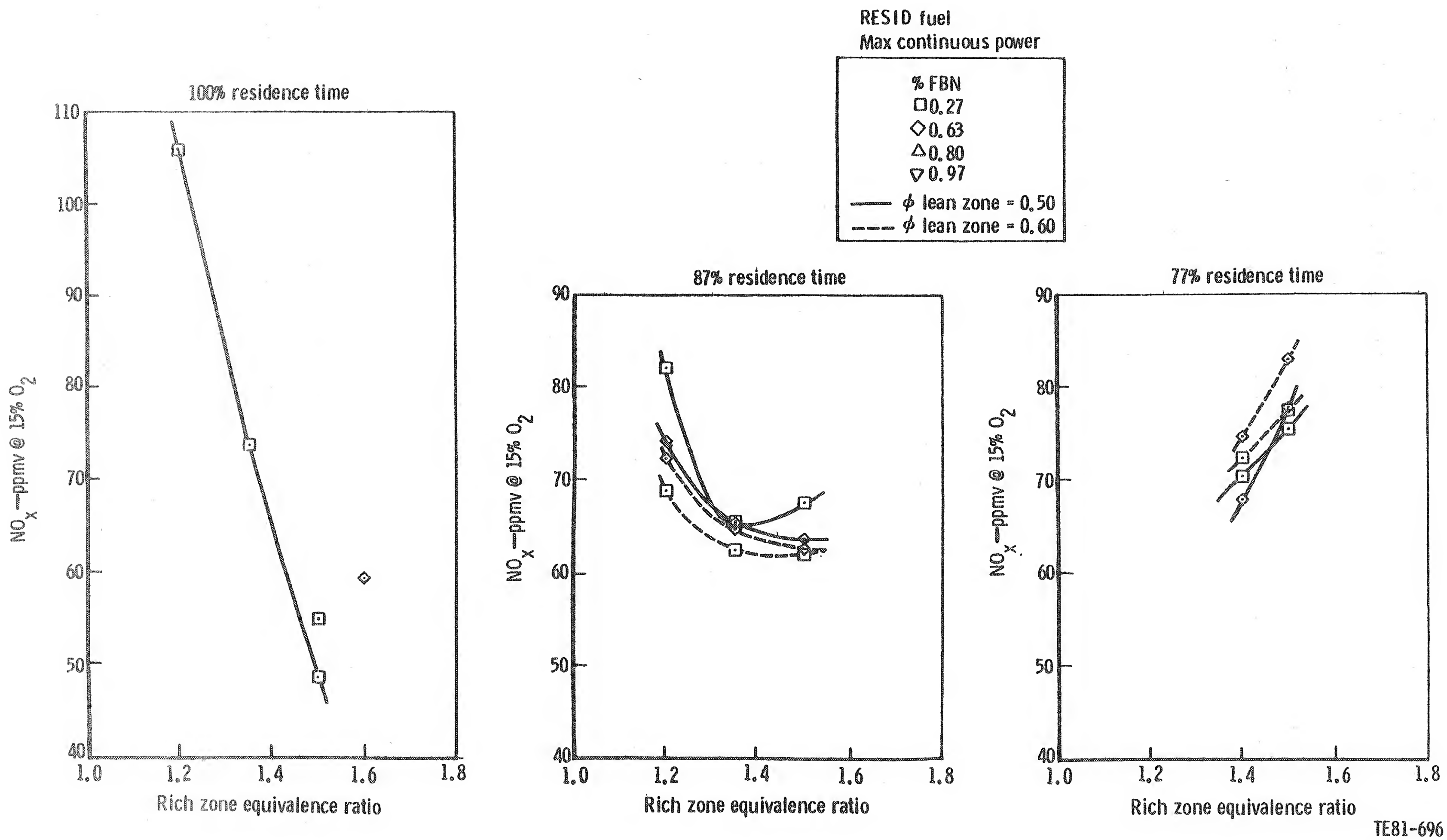

Figure 82. - Residence time parametric study--residence time variation.

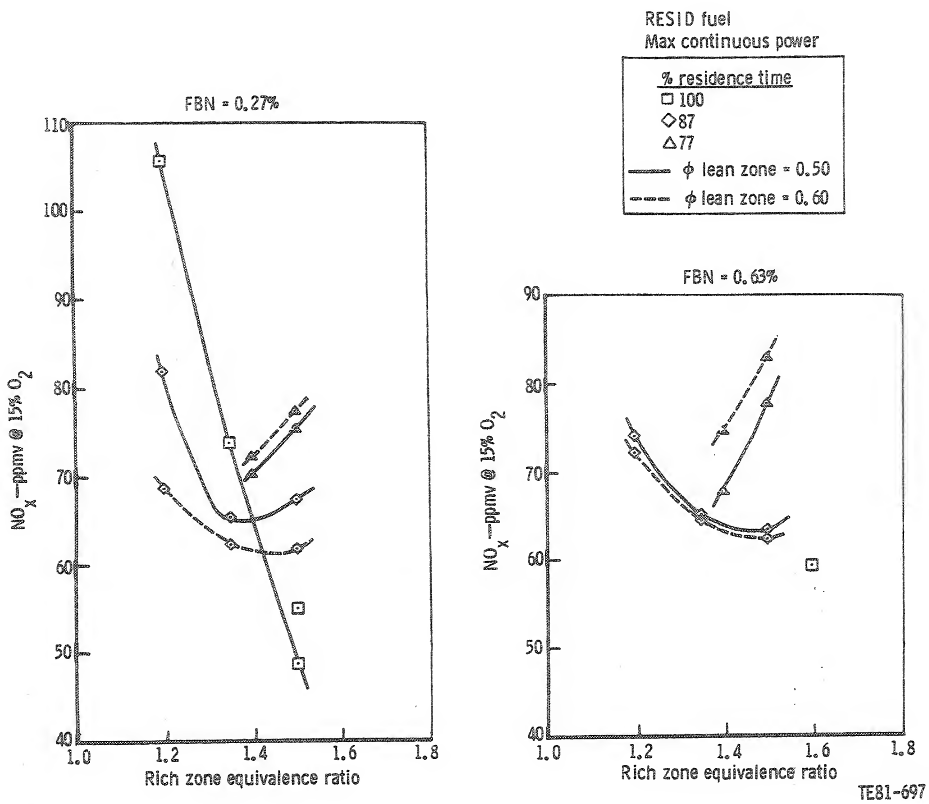

Figure 83. - Residence time parametric study--FBN variation.

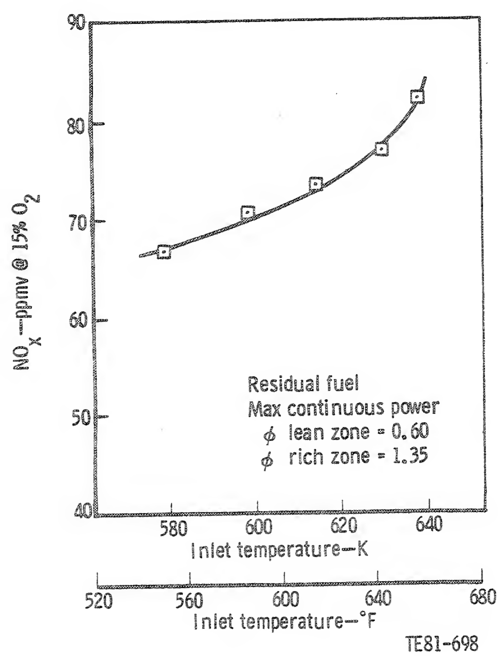

Figure 84. - Burner inlet temperature parametric study.

particularly with combustor operation in the rich ($\phi \geq 1.0$) regime; and engine-to-engine and combustor-to-combustor variations are magnified by variable-geometry operation as compared to a fixed-geometry design.

Minimum NO_x emissions as a function of rich zone VG settings, across the engine power range for two lean-zone equivalence ratios, are shown in Figures 85 and 86. These data indicate that while the magnitude of the minimum NO_x is relatively constant across the operating range, the open area (nozzle effective area) into the zone, required to achieve minimum NO_x, decreases dramatically as power level is decreased. This is necessary to maintain the proper rich equivalence ratio in the zone since engine flow factor and fuel rate vary.

In general, examination of the RQL test results reveals ranges of lean- and rich-zone equivalence ratios to assure proper combustor operation. These characteristics are: $0.4 \leq$ lean zone equivalence ratio ≤ 0.65 for combustor stability, starting and thermal NO_x control, and $1.05 \leq$ rich-zone equiva-

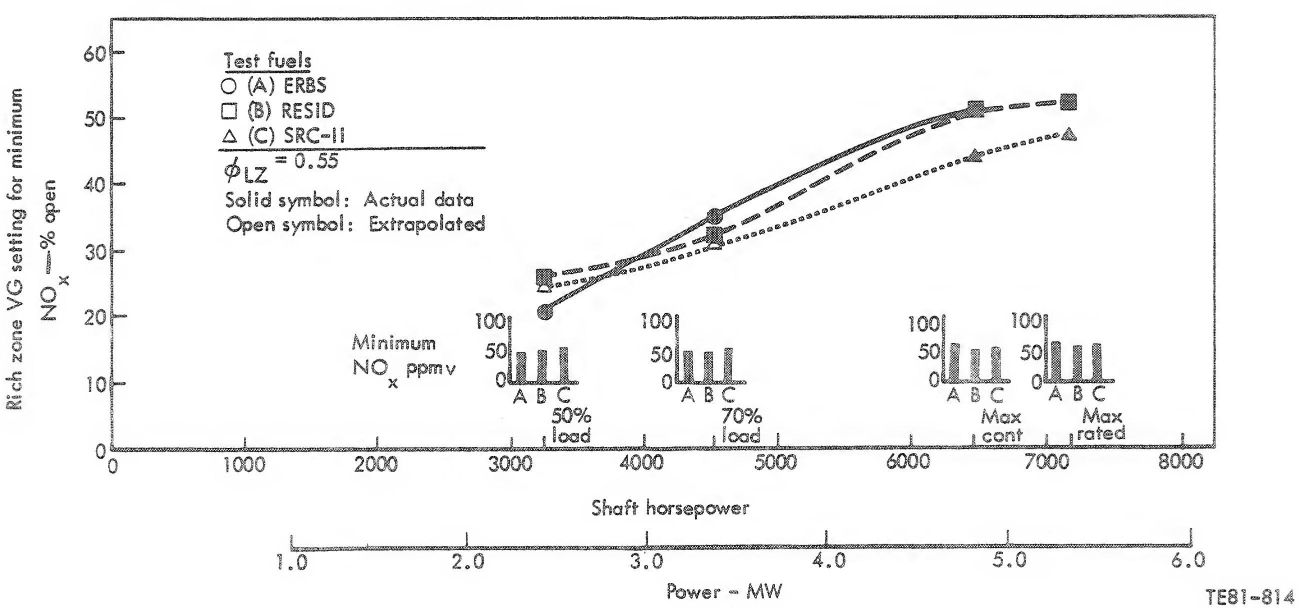

Figure 85. - Rich zone VG requirement for minimum NO_x vs power level (ϕ_{LZ} = 0.55).

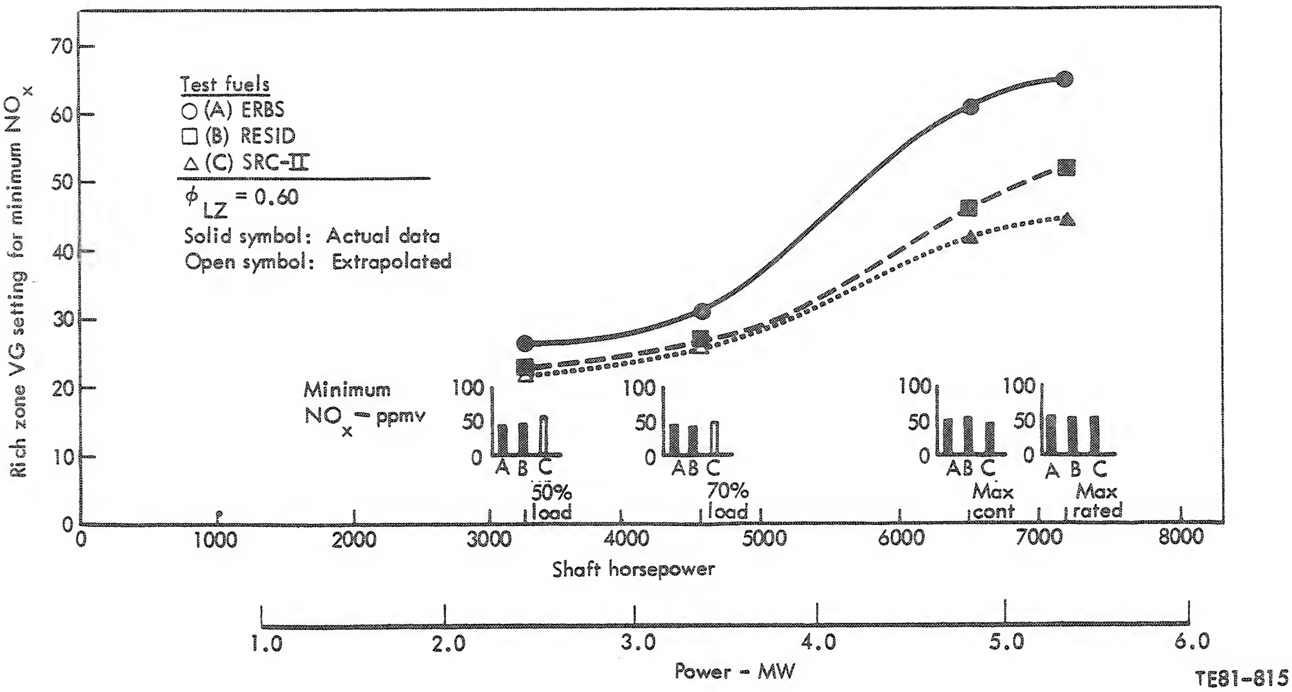

Figure 86. - Rich zone requirement for minimum NO_x vs power level (ϕ_{LZ} = 0.60).

lence ratio ≤ 1.8 for durability, NO_x control from FBN and carbon formation. Applying these constraints to an RQL combustor design it is possible to analyze performance over the engine operating range.

A matrix of variable-geometry settings was selected to generate theoretical operating lines for a fixed-geometry combustor. The geometry matrix selected for evaluation included:

Rich-zone VG settings	30-40-50% open
Mixer VG settings	0-10-20% open
Dilution-zone VG settings	30-40-50-60% open

A calculation procedure, based on experimentally determined airflow maps, was applied to these geometrical configurations which generated airflow splits, equivalence ratios and pressure drop data for each VG combination (36 data points) at five power levels.

Figure 87 illustrates the planes defined by the 36 data points for each power level in relation to lean-zone and rich-zone equivalence ratios. Limits for acceptable combustor performance, described earlier, are shown on the plot and thus define a range of optimized combustor operation. Specific VG setting groupings, listed in Table XI, are plotted on Figure 87 to illustrate theoretical fixed geometry combustor operation.

Table XI.

Selected fixed geometry combustor configurations.

Geometry setting, percent open						
Rich zone	Mixer	Lean zone	Power level	Rich-zone equivalence ratio	Lean-zone equivalence ratio	Liner pressure drop--%
40	0	40	Idle	0.411	0.186	10.0
			50%	0.944	0.429	7.7
			70%	1.102	0.500	7.3
			MC*	1.351	0.613	6.7
			MR*	1.447	0.657	6.5
40	10	40	Idle	0.441	0.180	8.7
			50	1.012	0.412	6.7
			70	1.182	0.481	6.3
			MC	1.448	0.590	5.9
			MR	1.550	0.631	5.7
40	20	40	Idle	0.474	0.173	7.5
			50	1.087	0.398	5.8
			70	1.267	0.464	5.5
			MC	1.551	0.568	5.1
			MR	1.661	0.609	5.0
40	0	50	Idle	0.436	0.198	8.9
			50	1.000	0.454	6.9
			70	1.167	0.530	6.5
			MC	1.429	0.649	6.0
			MR	1.530	0.694	5.9
40	10	50	Idle	0.466	0.190	7.8
			50	1.067	0.434	6.0
			70	1.245	0.507	5.7
			MC	1.524	0.621	5.3
			MR	1.631	0.664	5.2
40	20	50	Idle	0.498	0.182	6.8
			50	1.139	0.417	5.3
			70	1.329	0.487	5.0
			MC	1.625	0.596	4.7
			MR	1.740	0.638	4.5

*MC = max continuous power
MR = max rated power

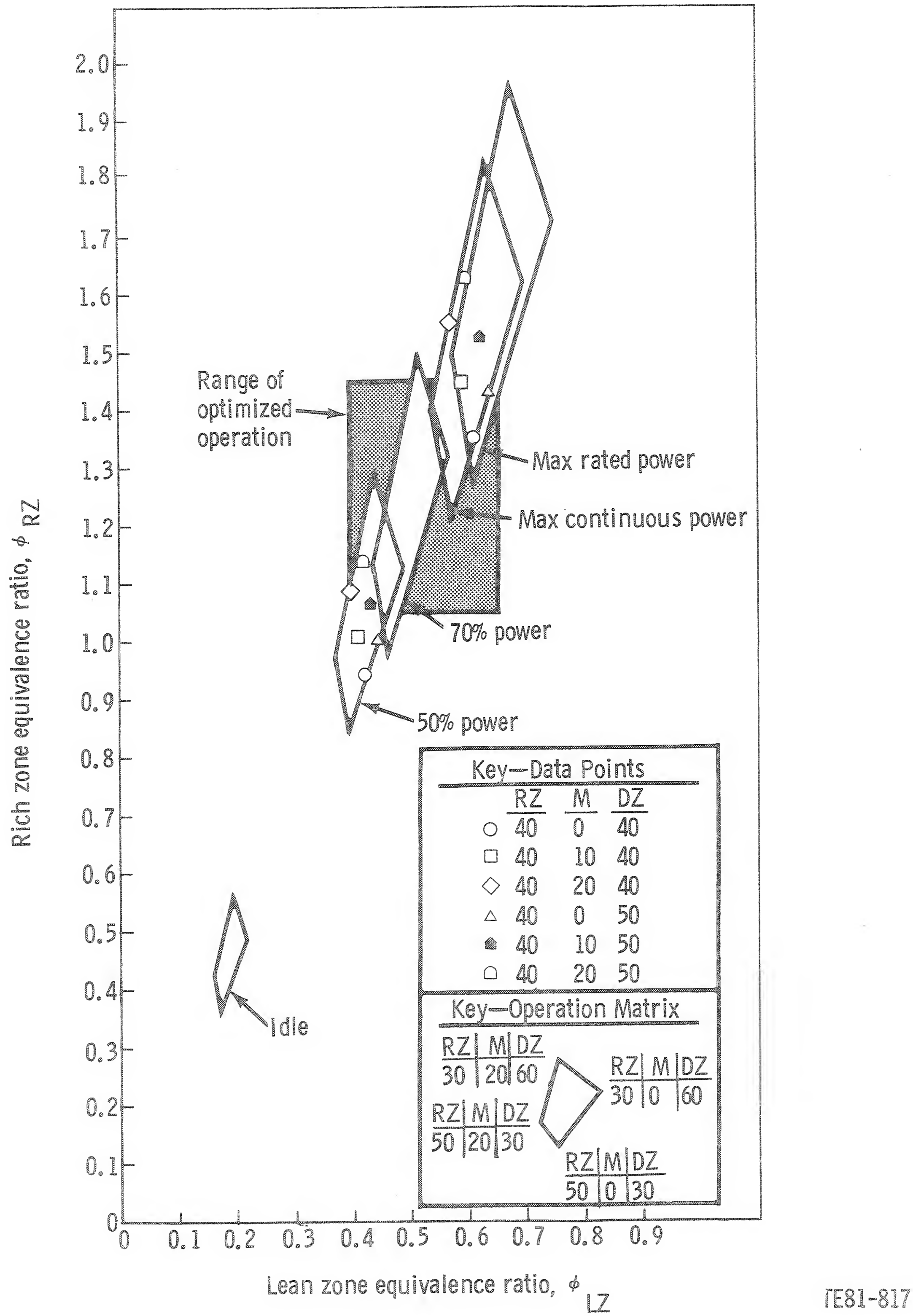

Figure 87. - Theoretical fixed-geometry operation at tested power levels.

It is apparent that no single fixed geometry configuration ideally satisfies all the operational requirements. One configuration, designated on Figure 87 as a solid symbol, closely fits the requirements from 50% power to the maximum continuous power condition; however, operation in the starting and idle regime will be extremely inefficient, if not impossible. Therefore, predicated on the above analysis of RQL test data, a fixed geometry combustor configuration appears to be inappropriate to meet all performance requirements over the engine operating range.

RQL Combustor Technology Application to Gas Turbine Engines

The RQL combustor tested in this combustor program was designed with engine application in mind. The wall cooling techniques incorporated into the RQL combustor were regenerative/convection, air film, and transpiration. The combustor surfaces enclosing the hot combustion gases were fabricated from sheets of high-temperature alloy steels. Haynes 188 alloy and Hastelloy X alloy were used in the rich zone. Hastelloy X alloy was used in the mixer, and Inconel 601 alloy was used to fabricate the Lamilloy transpiration cooling material in the lean and dilution zones. The performance of these materials and air cooling schemes was commendable throughout the test program.

Details of the RQL combustor were designed for experimental testing and ease of assembly, disassembly, modification, and repair if and when needed. To allow for these requirements, individual sections of the combustor were bolted together at several flange splitlines. In this manner, sections of the combustor could be easily removed for modification. An RQL combustor designed specifically for engine use would incorporate the salient features of the test rig combustor design, but the flanges would be replaced by welded seams, and the bulk and weight of the rig combustor would be removed.

As discussed in the previous section, elimination of one or more variable-geometry systems would be very desirable in any engine application. Additional evaluations will be required before any of the variable-geometry systems can be removed.

For the variable-geometry systems required in an engine combustor, further development will be required to improve the durability of the moving parts. Also, development to minimize leakage must be conducted. The application of coatings or lubricants must be investigated to reduce the friction and wear of the bands and the base metal. Actuating mechanisms must be compatible with the engine control systems. The DDA Model 570-K industrial engine currently uses a hydraulic actuating system to position several stages of variable-geometry compressor vanes.

In any engine combustor design, allowances must be included for maintenance and replacement of parts requiring frequent attention such as fuel nozzles, ignitors, actuators, or, possibly, transition pieces. Ease of access to components will greatly influence the design of rigid attachment points and slip joints for thermal growth. The RQL rig combustor in this program used a sliding joint between the fuel nozzle and the entrance section of the rich zone. Removal of the fuel nozzle was relatively easy, requiring only the removal of a circle of bolts, but air leakage past the sliding joint remains a problem area.

Continuing development of the combustor, in Phase II of this program, must address to this and other combustor design areas.

RQL Combustor Installation into a Gas Turbine Engine

Preliminary studies were conducted to investigate the installation of RQL combustors in an existing gas turbine engine. Using the RQL combustor dimensions and sizing, installation layout drawings were made. The removal of an existing combustor system and the insertion of RQL combustors is depicted in Figure 88. In this layout, a series of RQL combustors are splayed out over the compressor at a 15-deg angle. Suitable housings would then cover the combustors, creating an expanded combustor outer case. Access ports or sectors in the case would be provided to give access to the individual cans and their associated subsystems. Individual actuators are shown for each variable-geometry system on each of the combustor cans.

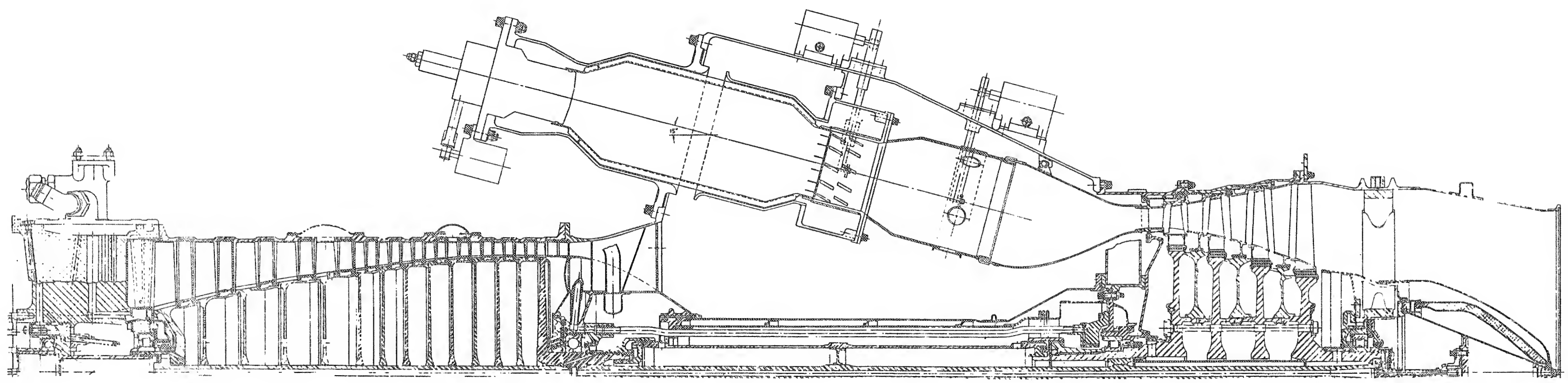

Figure 88. Multiple-can engine installation of RQL combustor.

In another installation, shown in Figure 89, the RQL combustor system is represented by a single large can positioned normal to the engine center line. A single-can system offers many advantages to an industrial or utility gas turbine installation. Cooling can be minimized because of the favorable surface-to-volume ratio of a single can, or the combustor surfaces can be cooled to lower temperatures for significant increases in combustor life. If variable geometry is necessary, only one set of actuators would be needed. This would eliminate the problems of air distribution balance and mechanical repeatability of the multiple-can combustor. Fuel injection might be possible from a single fuel nozzle, but a cluster of nozzles in the dome of the rich zone could be more appropriate. The transfer of the hot combustor exhaust to the turbine inlet requires some development, but DDA has considerable experience with a similar distribution system in its IGT 404/505 industrial engine series.

RQL Combustor Impact on Other Engine Systems

The translation of the RQL combustor technology into engine hardware affects engine systems besides the combustion system. Any type of variable geometry required by the RQL combustor will have a major impact on the engine control system. Having variable geometry in the combustor requires sensing additional parameters or applying currently measured parameters to provide the inputs to a new set of logic for the adjustment of the variable-geometry systems and, ultimately, the stoichiometry within the RQL combustor. Additional actuators would also be required for the combustor over and above the other variable-geometry actuators used in the engine, such as the compressor vane hydraulic actuator.

For present engines not burning high viscosity fuels or fuels possessing high levels of corrosive compounds from either wider specification or synthetic fuels, the entire fuel system must be redeveloped for these types of fuels. Engine start-up and shut-down present their own special problems for the fuel system, requiring additional auxiliary heating systems, new fuel purging systems, or dual fuel systems to solve these problems not previously encountered with the historically better grades of gas turbine fuels.

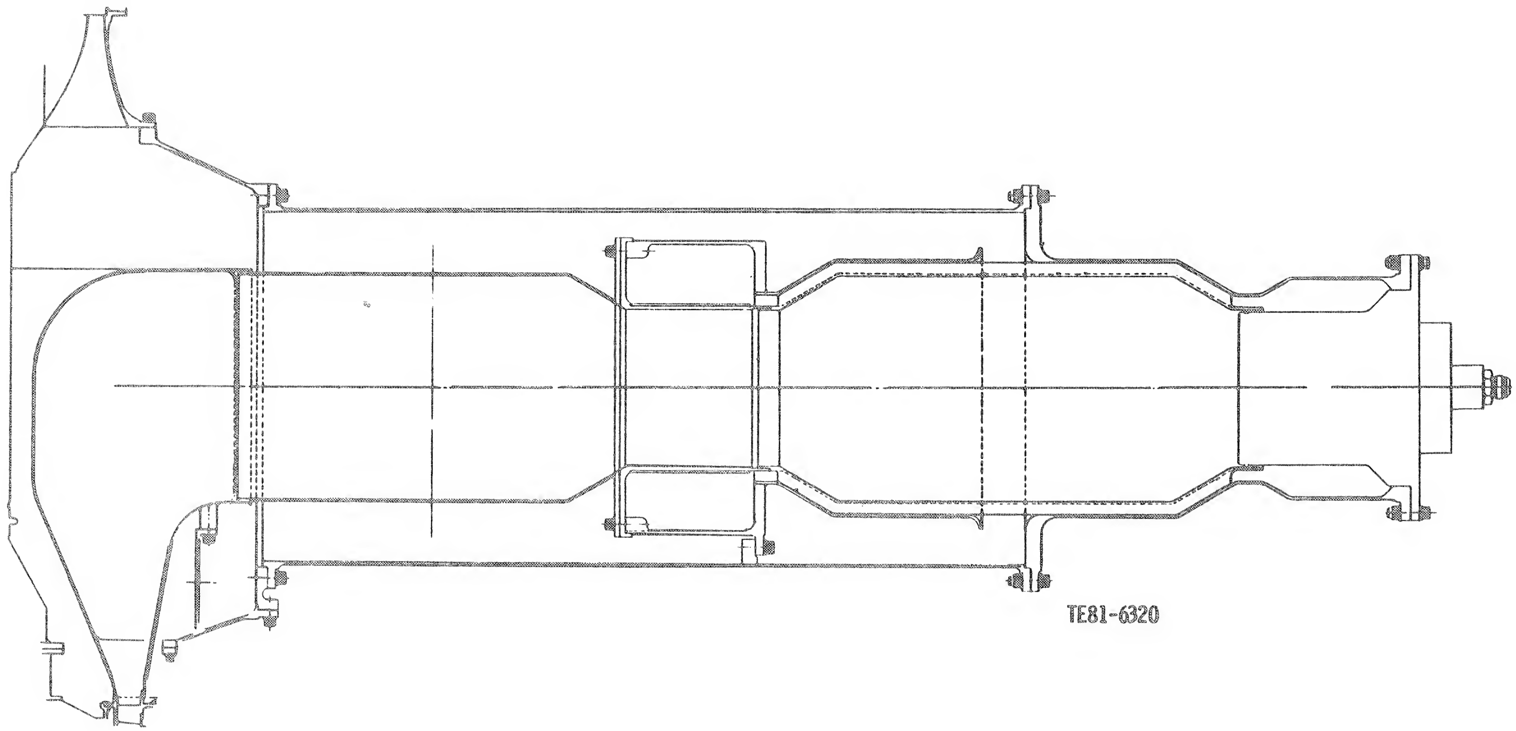

Figure 89. Single-can engine installation of RQL combustor.

Air handling from the compressor diffuser to the combustor cans may also require development. Balancing of the compressor discharge air to each of the outward-mounted combustor cans must be accomplished to maintain the carefully controlled stoichiometry in the combustors. Additional pressure losses due to the longer path the air must travel from the compressor to the combustor must be considered as well as the thermal loss due to the larger combustor outer case and its associated larger surface area.

Therefore, gas turbine application of the unique combustion technology demonstrated with the RQL combustor will require a careful development program to avoid detrimental effects to the satisfactory performance of today's industrial and utility gas turbine engines.

CONCEPT II--PREHEAT RQL

The purpose of the Concept II--Preheat RQL combustor was to provide additional heat energy to vaporize the RESID fuel in the event that the Concept I--RQL combustor would not perform well on RESID fuel. The RQL combustor did not show any difficulty with RESID fuel, thus the Preheat RQL combustor was not tested.

As described in Section II--Combustor Designs, the Preheat RQL combustor components were designed and fabricated (see Figure 20). Cold flow calibrations of the preheat section of the combustor were conducted for both the air blast fuel nozzle, Figure 90, and for the air assist fuel nozzle, Figure 91. These flow maps were determined by assembling the hardware as shown in Figure 92. The front half of the rich zone was removed from the RQL combustor. The preheat hardware was then assembled and installed on the rich zone at the Concept I flange. A fuel nozzle was then installed in the end of the preheat-rich zone assembly. This assembly was the RQL combustor rich-zone flow system as it would have been run. The preburner air assist fuel nozzle was installed, but no assist air was connected due to the very low flow involved.

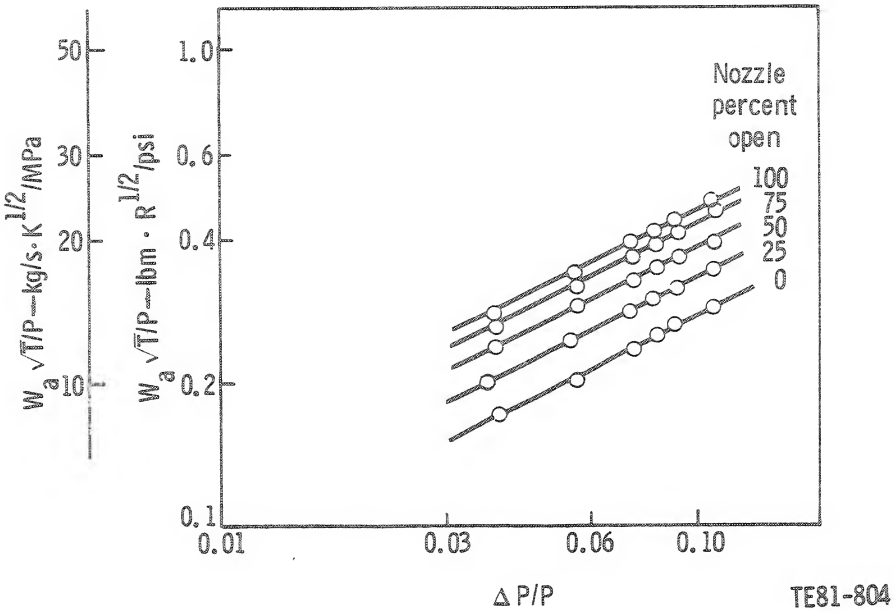

Figure 90. - Flow calibration of Concept II--Preheat RQL combustor--total rich zone air system with air blast fuel nozzle.

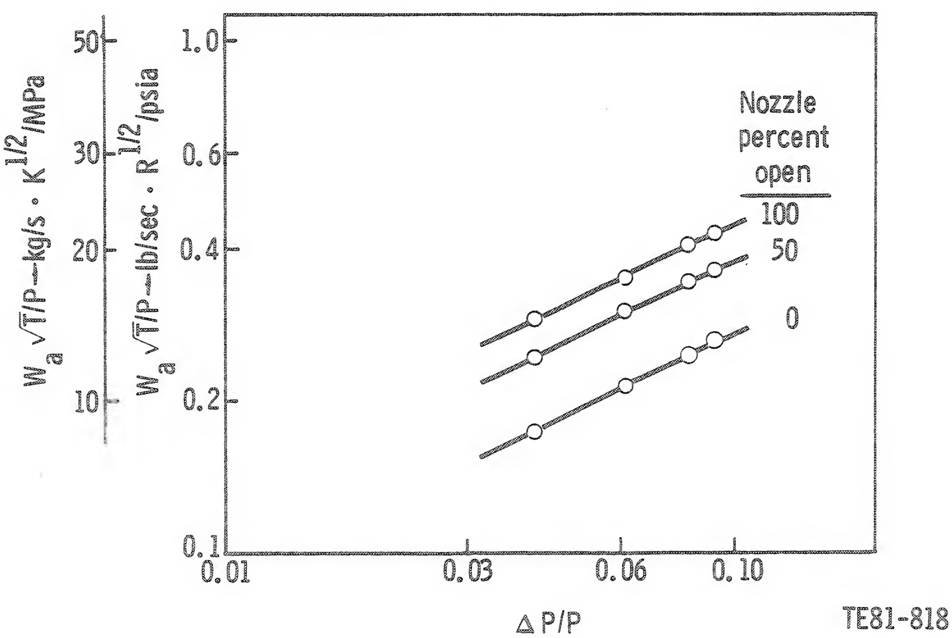

Figure 91. - Flow calibration of Concept II--preheat RQL combustor--total rich zone air system with air assist fuel nozzle.

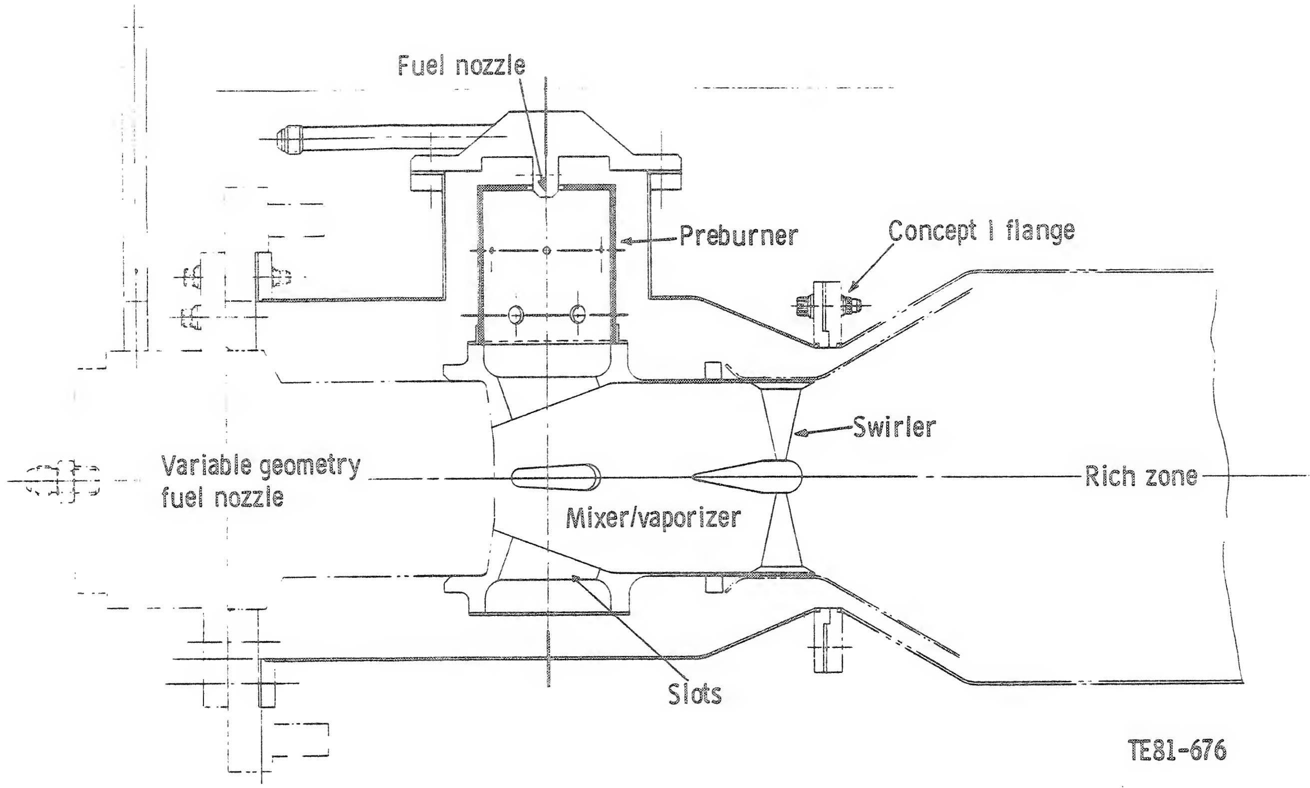

Figure 92. - Concept II fuel preparation chamber design--side view.

The addition of the preburner air to the rich zone reduced the rich-zone equivalence ratios by approximately 35%. Thus for similar settings of the variable geometry systems, an RQL combustor rich zone equivalence ratio of 2.5 would decrease to a 1.6 ratio for the preheat RQL combustor. Ample range was still available to test the preheat RQL combustor at rich zone equivalence ratios of interest.

CONCEPT III--LEAN/LEAN

The lean/lean combustor was the third combustor designed for this program and the second combustor concept tested. This combustor was tested only on the ERBS fuel, as control of FBN conversion was not intended. Using the variable-geometry air blast nozzle, the combustor air distribution was selected to vary the primary-zone equivalence ratio from 0.6 to 0.7 at maximum continuous power. The intermediate-zone variation ranged from 0.48 to 0.51, for the nozzle open to closed, respectively.

Eleven data points were recorded for the lean/lean combustor: three at idle, four at 50% load, two at 70% load, and two approaching maximum continuous. Measured maximum combustor liner metal temperatures over 1370 K (2000°F) at weld points prevented attaining design point fuel flow at the maximum continuous power condition. No attempt was made to obtain data at maximum rated power conditions.

A check of mechanical and chemical fuel-air ratios for each data point in Figure 93 shows that there was very good correlation between values at each data point. The chemical fuel-air values were well within a 10% variability band of the mechanically measured values. Therefore the exhaust gases concentrations measured were representative of the proportions of each constituent in the exhaust duct.

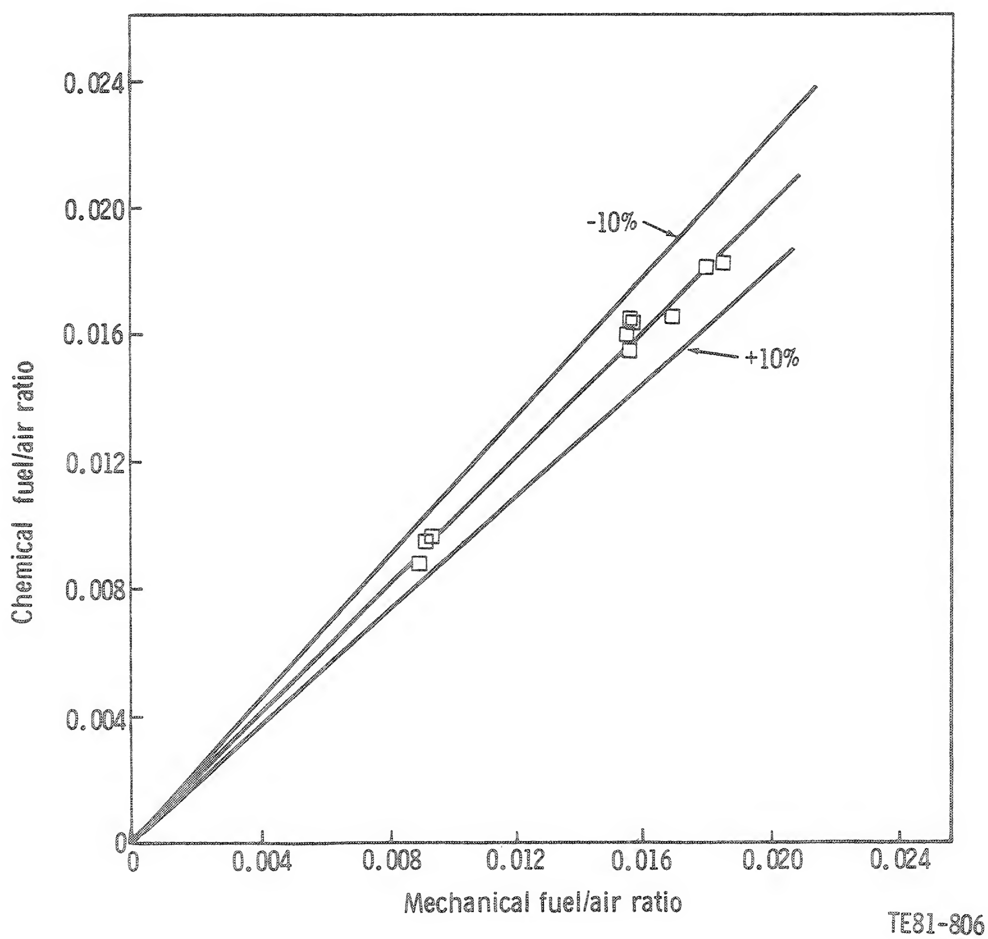

Figure 93. - Chemical versus mechanical fuel-air ratios for performance data of lean/lean combustor on ERBS fuel.

Data plots for lean/lean combustor performance are given in Figures 94 and 95. The variable-geometry fuel nozzle, being the only variable-area device on the lean/lean combustor, had inadequate range to maintain a desired primary zone over the engine range for good combustion. Thus, at idle the CO and UHC emissions were quite high and of nearly equal concentrations, indicating that much of the primary zone was not burning, and thus the combustion efficiencies were quite low.

Performance of the lean/lean combustor above idle was good: CO, UHC, and smoke, were all quite low. At the higher settings, CO emissions were in the order of 30 ppm, and UHC emissions were in the range of 60 ppm. NO_x emissions were high beginning with the 50% load data points. With a NO_x goal of 90 ppm, the lean/lean combustor was only slightly below the goal at 50%

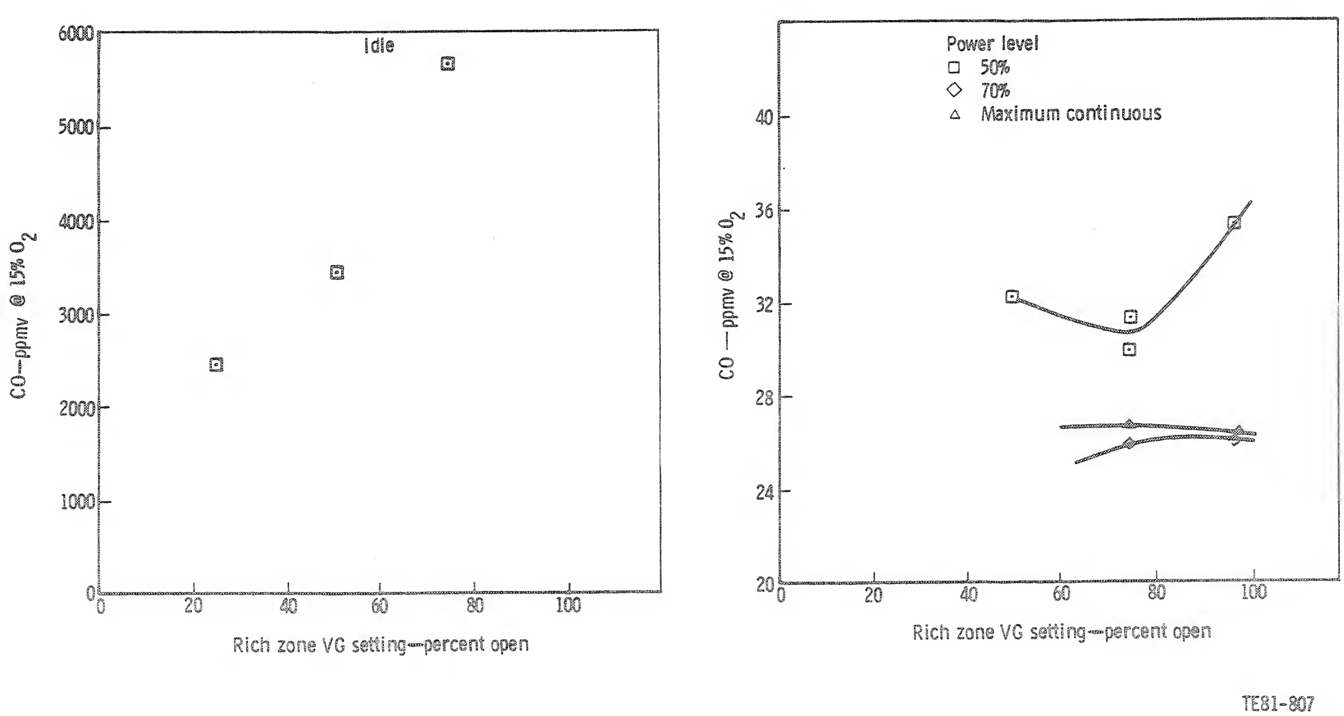

Figure 94. - Lean/lean combustor performance on ERBS fuel.

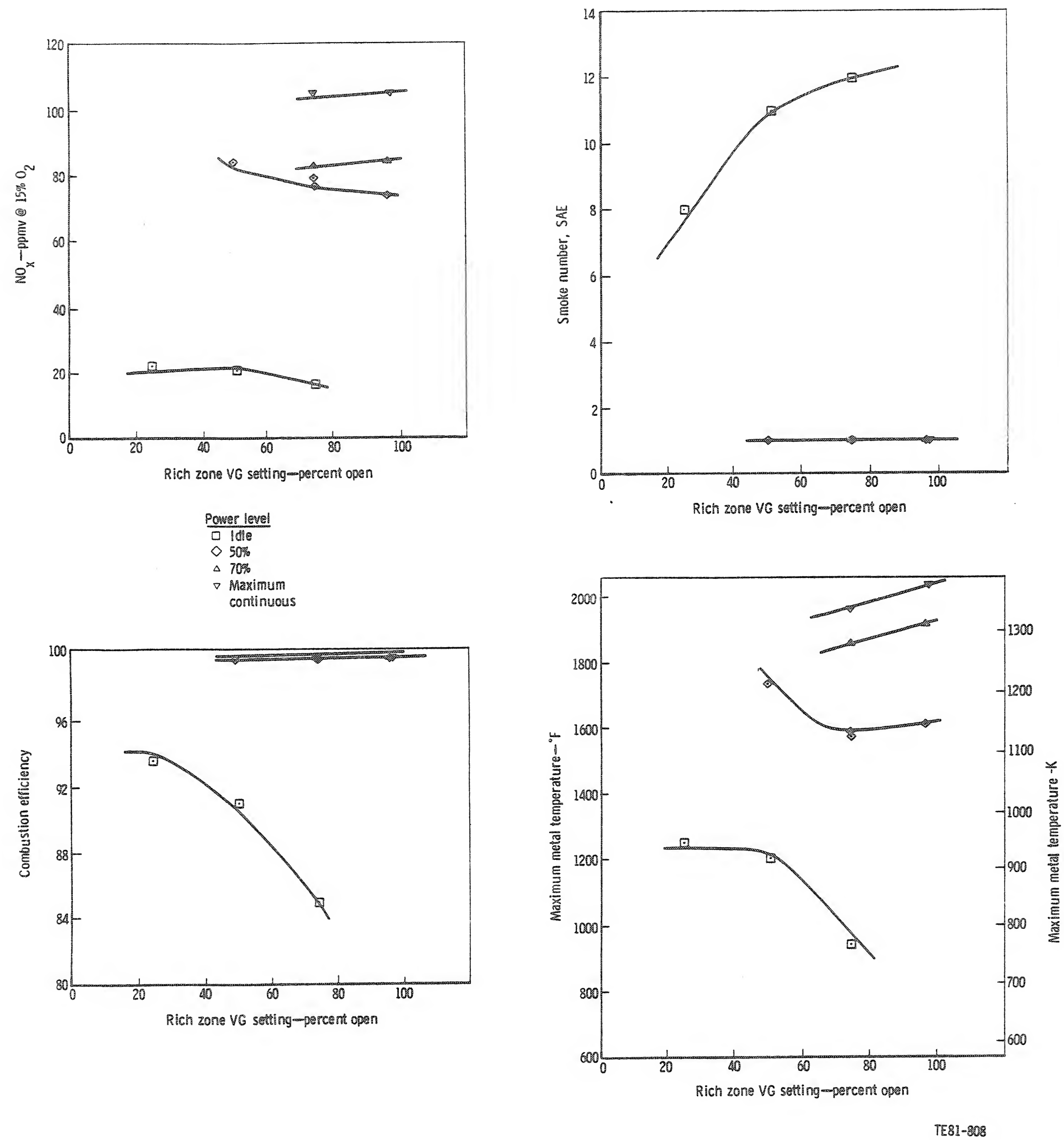

Figure 95. - Lean/lean combustor carbon monoxide on ERBS fuel.

and 70% load. By the time the test terminated due to high indicated liner metal temperatures, the NO_x levels were already at 105 ppm and would probably have increased further until rated fuel flow was reached.

VI. CONCLUSIONS

A fuel-flexible, variable-geometry, air-staged, regenerative/convection- and transpiration-cooled combustor has been designed and tested. This unique combustor is denoted as a rich/quench/lean (RQL) combustor. The goal of this combustor is to burn residual and synthetic fuels containing bound nitrogen while meeting environmental standards.

The RQL combustor exhaust emissions results are summarized in Table XII. The combustor produced emissions levels well below both maximum EPA limits and program goals when operating on each of the three base fuels: ERBS, RESID, and SRC-II. Smoke levels were below a smoke number of 10 (one-half the program goal) at all operating conditions. Carbon monoxide levels were below 100 ppm at idle and below 50 ppm at higher power conditions. Unburned hydrocarbon emissions were less than 50 ppm at all conditions tested.

Nitrogen oxide emissions were significantly lower than the EPA maximum allowable level of 180 ppm at all conditions except at idle, where variable-geometry restrictions did not permit rich-zone equivalence ratios sufficiently above unity to suppress the thermal NO_x. At the optimum configuration for minimum NO_x, the RQL combustor is essentially insensitive to the quantity of FBN in the fuel. This was shown to be the case for the inherent FBN in each fuel, which varied from almost zero to 0.88% by weight. The addition of pyridine to the ERBS fuel, simulating FBN levels up to 0.72% by weight, produced only small increases in exhaust NO_x of approximately 15 ppm, thus demonstrating the NO_x suppression performance of the RQL combustor technology.

Parametric testing of the RQL combustor revealed the following variations of NO_x emissions at the rich-zone equivalence ratios at which minimum NO_x occurred:

- o NO_x varied in an inverse manner with changes in pressure drop
- o NO_x varied in a direct manner with changes in rich-zone residence time

Table XII.

Program Summary.

Conditions: Rich/quench/lean (RQL) combustor
6% pressure drop
0.60 lean-zone equivalence ratio
Maximum continuous power conditions

	Test fuels		
	ERBS	Residual	SRC-II
FBN content, wt %	0.013	0.27	0.88
Maximum EPA NO_x, ppm at 15% O_2	180	230	230
Program NO_x goal, ppm at 15% O_2	90	230	230
Minimum NO_x measured, ppm at 15% O_2	49	53	50
Program smoke goal, SAE smoke number(SN)	20	20	20
Measured smoke, SAE SN	5	3	3
Program combustion efficiency goal, %	99	99	99
Demonstrated combustion efficiency, %	99.9	99.9	99.9
Rich-zone equivalence ratio at minimum measured NO_x	1.25	1.40	1.35
Measured CO, ppm at 15% O_2	22	25	25
Measured unburned hydrocarbons, ppm at 15% O_2	24	7	6
Rich-zone maximum metal temperature, K (F)	1,015 (1,366)	1,170 (1,644)	1,110 (1,541)

For rich-zone equivalence ratios on the lean side of the NO_x minimum, increases in FBN tended to reduce the concentration of NO_x in the exhaust. For rich-zone equivalence ratios on the rich side of the NO_x minimum, increases in FBN tended to increase the NO_x concentrations in the exhaust.

Even though the objective for this phase of the program was to demonstrate only durability potential, the RQL combustor in actuality demonstrated excellent hardware durability during the recording of 594 separate data points on all three of the experimental fuels. Most of this testing was conducted at maximum continuous (maximum base load) conditions. All three variable-geometry mechanisms (nozzle, mixer, and dilution) operated satisfactorily through the entire testing program. Through variable-geometry actuation of the three mechanisms, rich-zone equivalence ratios at maximum continuous power conditions could be varied from 1.0 to 2.9 at reasonable pressure drops (4% to 7%). Lean-zone equivalence ratios could also be varied from 0.4 to 1.0.

APPENDIX

Summarized in this appendix are the performance and parametric test data from the RQL combustor testing. Each data point requires three lines of description. The second line in each table is designated "A" table, the third line, "B" table. Each line for a data point begins with its reading number on the left. The comments below describe the parameters in the following tables.

Line 1

Reading number	A six-digit year/month/day number followed by a three-digit initial record number
Hardware identification	All data are for Liner Concept I, the rich/quench/lean (RQL) combustor. The fuel nozzle is the air blast (AB) nozzle and is fundamentally unchanged
Fuel type	Fuels were used either singly or in combination: A--ERBS middle distillate B--RESID residual C--SRC-II coal-derived liquid P--two-vinyl pyridine for FBN simulation
Fuel, % H	Percent hydrogen content in fuel or fuel blend
Fuel, % N	Percent nitrogen content in fuel or fuel blend
Fuel, LHV	Lower heating value of fuel or fuel blend (computed by mass averaging)
Fuel temp, °F	Fuel temperature measured at the fuel inlet fitting to the test rig
Simulated engine power condition	Model 570 steady-state conditions

W NOZ, lb/sec (if air assist)	Fuel nozzle assist air flow (if air assist nozzle)
TINLET, °F	Combustor inlet total temperature
PINLET, psia	Combustor inlet total pressure
W fuel P, lb/sec	Fuel mass flow entering rich (primary) zone through fuel nozzle
W air P, lb/sec	Air mass flow entering rich (primary) zone through fuel nozzle
W fuel S, lb/sec	Fuel mass flow entering lean (secondary) zone (not used in RQL combustor)
W air S, lb/sec	Air mass flow entering lean (secondary) zone through rich zone plus mixer

<u>Line 2 (A tables)</u>

Reading number	Same as in line 1
Primary equivalence ratio	Equivalence ratio in rich (primary) zone $(f/a)_{rz} \div (f/a)_{st}$
Secondary equivalence ratio	Equivalence ratio in lean (secondary) zone $(f/a)_{lz} \div (f/a)_{st}$
Overall equivalence ratio	Equivalence ratio for entire combustor $(f/a)_{o} \div (f/a)_{st}$

Primary res. time, ms

Rich (primary) zone residence time based on combustor inlet conditions, rich zone reference velocity, and rich zone volume and area

$$t_p \text{ (ms)} = \frac{Vol_p}{A_p \cdot Vel_p}$$

Vol_p and A_p are volume and area of rich (primary) zone determined from hardware

Secondary res. time, ms

Lean (secondary) zone residence time based on combustor inlet conditions, lean zone reference velocity, and lean zone volume and area

$$t_s \text{ (ms)} = \frac{Vol_s}{A_s \cdot Vel_s}$$

Primary ref. velocity (ft/sec)

Rich (primary) zone velocity based on rich zone air mass flow, inlet temperature and pressure, and average rich-zone cross-sectional area

$$Vel_p \text{ (ft/sec)} = \frac{M_{air_p} \cdot R_{air} \cdot T_{in}}{P_{in} \cdot A_p}$$

Secondary ref. velocity (ft/sec)

Lean (secondary) zone velocity based on lean zone air mass flow, inlet temperature and pressure, and average lean-zone cross-sectional area

$$Vel_s \text{ (ft/sec)} = \frac{M_{air_s} \cdot R_{air} \cdot T_{in}}{P_{in} \cdot A_s}$$

Exit temperature, °F

Average reading of 26 combustor outlet temperature thermocouples

Exit pressure	Average of two static pressures in combustor lean zone
Specific humidity	Ratio of grams of water in inlet air per gram of dry air, computed from $$S = \frac{pv}{\frac{M_{air}}{M_{H_2O}}(B - pv)}$$ pv = vapor pressure of water in inlet air B = barametric pressure
Combustor delta P, psi	Measured pressure drop across combustor in psi
Liner temperature, °F	Maximum measured metal temperature of 33 combustor liner thermocouples
CO, ppm	Measured carbon monoxide in exhaust
CO_2, ppm	Measured carbon dioxide in exhaust
HC, ppm	Measured unburned hydrocarbons in exhaust (C_1 base as CH_4)
NO_x, ppm	Measured total nitrogen oxides in exhaust (NO_x as NO_2)
NO_x, ppmc	Total nitrogen oxides in exhaust corrected to 15% O_2 and for inlet temperature, pressure, and humidity per EPA Reference Method 20

Line 3 (B tables)

Reading number	Same as in line 1

% N conversion — Ratio of corrected NO_x divided by NO_x equivalent of nitrogen in the fuel (not computed for % FBN less than 0.014% or ERBS fuel)

$$\% \text{ N conversion} = \frac{NO_x \text{ (ppmc)}}{\left[\frac{(f/a)_o}{1 + (f/a)_o}\right] \cdot \% N_F \cdot \frac{M_{exh}}{M_{NO_2}} \times 100}$$

where

NO_x (ppmc) = corrected NO_x as NO_2

$(f/a)_o$ = overall fuel/air ratio

$\% N_F$ = percent nitrogen in fuel by weight

M_{exh} = molecular weight of exhaust gas, = $f\ (f/a_o$, H/C of fuel)

M_{NO_2} = 46.008, molecular weight of NO_x as NO_2

Combustion efficiency, % — Percent combustion efficiency, computed from corrected exhaust gas emissions (NO_x, CO, CH_x), CO_2, heat release rate of fuel (Btu/lb-mole) based on C_1 fuel molecule

Smoke number — Smoke number per ARP 1179

Pattern factor — Circumferential pattern factor of exhaust

$$PF_c = \frac{T_{max} - T_{avg}}{T_{avg} - T_{in}}$$

FARR — Ratio of overall fuel-air ratio computed from exhaust gas analysis to overall fuel-air ratio determined from airflow and fuel flow measurements

Desired primary zone equivalence ratio	Rich (primary) zone equivalence ratio desired when test point was recorded
Desired lean zone equivalence ratio	Lean (secondary) zone equivalence ratio desired when test point was recorded

Table XIII.

RQL combustor performance data--ERBS fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801008193	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	148.	MAX CONTINUOUS	0.0	634.	162.6	0.033	0.848	0.0	2.038
801008208	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	148.	MAX CONTINUOUS	0.0	637.	162.8	0.083	0.674	0.0	2.120
801008223	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	150.	MAX CONTINUOUS	0.0	645.	162.8	0.082	0.904	0.0	2.115
801008238	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	152.	MAX CONTINUOUS	0.0	644.	162.7	0.082	0.942	0.0	2.071
801008253	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	151.	MAX CONTINUOUS	0.0	645.	161.6	0.083	0.960	0.0	2.176
801008268	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	150.	MAX CONTINUOUS	0.0	643.	161.4	0.083	1.009	0.0	2.162
801008283	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	151.	MAX CONTINUOUS	0.0	644.	165.3	0.083	1.014	0.0	2.246
801008298	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	148.	MAX CONTINUOUS	0.0	644.	165.0	0.083	0.961	0.0	2.254
801008313	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	150.	MAX CONTINUOUS	0.0	645.	164.8	0.083	0.939	0.0	2.235
801008328	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	149.	MAX CONTINUOUS	0.0	645.	163.9	0.083	0.866	0.0	2.201
801008343	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	151.	MAX CONTINUOUS	0.0	646.	163.9	0.083	0.850	0.0	2.178
801008358	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	150.	MAX CONTINUOUS	0.0	647.	163.7	0.083	0.824	0.0	2.169
801008373	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	154.	MAX RATED	0.0	667.	175.8	0.092	0.935	0.0	2.336
801008388	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	153.	MAX RATED	0.0	670.	176.0	0.092	1.003	0.0	2.394
801008403	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	153.	MAX RATED	0.0	672.	175.5	0.092	1.096	0.0	2.391
801008418	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	156.	MAX RATED	0.0	674.	175.3	0.092	1.100	0.0	2.364
801008433	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	153.	MAX RATED	0.0	675.	174.8	0.092	1.004	0.0	2.373
801008448	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	153.	MAX RATED	0.0	676.	174.8	0.092	0.944	0.0	2.388
801008463	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	156.	70% LOAD	0.0	597.	133.6	0.059	0.719	0.0	1.680
801008480	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	156.	70% LOAD	0.0	595.	133.6	0.059	0.687	0.0	1.687
801008495	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	155.	70% LOAD	0.0	588.	133.5	0.059	0.677	0.0	1.621
801008510	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	157.	70% LOAD	0.0	586.	133.5	0.059	0.645	0.0	1.551
801008525	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	155.	70% LOAD	0.0	584.	133.5	0.059	0.625	0.0	1.506

Table XIII (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801008540	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	155.	70% LOAD	0.0	579.	132.9	0.059	0.597	0.0	1.553
801008555	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	156.	70% LOAD	0.0	579.	133.0	0.059	0.603	0.0	1.511
801008569	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	157.	70% LOAD	0.0	577.	133.1	0.059	0.630	0.0	1.514
801008584	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	157.	70% LOAD	0.0	576.	133.1	0.059	0.656	0.0	1.510
801008599	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	155.	70% LOAD	0.0	573.	133.0	0.059	0.672	0.0	1.530
801008614	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	154.	70% LOAD	0.0	573.	133.0	0.059	0.695	0.0	1.525
801008629	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	155.	70% LOAD	0.0	571.	132.9	0.059	0.735	0.0	1.553
801008644	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	161.	50% LOAD	0.0	546.	113.6	0.045	0.558	0.0	1.237
801008659	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	159.	50% LOAD	0.0	543.	113.5	0.045	0.542	0.0	1.205
801008674	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	164.	50% LOAD	0.0	541.	113.4	0.045	0.522	0.0	1.141
801008689	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	160.	50% LOAD	0.0	538.	113.3	0.045	0.496	0.0	1.156
801008704	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	161.	50% LOAD	0.0	528.	113.1	0.045	0.481	0.0	1.102
801008719	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	158.	50% LOAD	0.0	525.	112.9	0.045	0.458	0.0	1.143
801008734	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	158.	50% LOAD	0.0	520.	112.7	0.045	0.457	0.0	1.159
801008749	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	156.	50% LOAD	0.0	509.	112.4	0.045	0.484	0.0	1.165
801008764	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	157.	50% LOAD	0.0	508.	112.3	0.045	0.500	0.0	1.186
801008779	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	157.	50% LOAD	0.0	506.	112.4	0.045	0.519	0.0	1.170
801008794	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	158.	50% LOAD	0.0	505.	112.3	0.045	0.537	0.0	1.173
801008809	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	155.	50% LOAD	0.0	500.	112.0	0.045	0.556	0.0	1.198
801008824	LINER I-E, NOZ AB-F	AP	12.56	0.71	18125.	153.	50% LOAD	0.0	489.	112.2	0.045	0.468	0.0	1.120
801008839	LINER I-E, NOZ AB-F	AP	12.61	0.60	18156.	151.	50% LOAD	0.0	487.	112.1	0.045	0.467	0.0	1.152
801008854	LINER I-E, NOZ AB-F	AP	12.68	0.44	18203.	153.	50% LOAD	0.0	486.	112.1	0.046	0.464	0.0	1.134
801008869	LINER I-E, NOZ AB-F	AP	12.76	0.27	18251.	154.	50% LOAD	0.0	484.	111.8	0.046	0.462	0.0	1.140

Table XIII (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801008884	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	152.	50% LOAD	0.0	482.	111.7	0.046	0.462	0.0	1.162
801008899	LINER I-E, NOZ AB-F	A	12.88	0.01	18327.	152.	50% LOAD	0.0	480.	111.7	0.046	0.459	0.0	1.171

Table XIII-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801008193	1.41	0.57	0.33	82.	15.	13.	31.	1598.	153.	0.00318	9.99	1420.	29.	47210.	44.	68.	54.
801008208	1.37	0.56	0.33	79.	15.	13.	32.	1587.	153.	0.00311	9.72	1416.	28.	45370.	35.	65.	53.
801008223	1.32	0.56	0.33	76.	15.	14.	32.	1567.	153.	0.00316	9.75	1373.	30.	49790.	39.	67.	50.
801008238	1.26	0.57	0.33	73.	15.	14.	31.	1556.	153.	0.00318	9.80	1366.	29.	50330.	31.	67.	49.
801008253	1.24	0.55	0.33	71.	14.	14.	33.	1547.	152.	0.00316	9.38	1315.	30.	53520.	31.	77.	54.
801008268	1.19	0.55	0.34	68.	14.	15.	33.	1575.	152.	0.00322	9.58	1296.	29.	53020.	27.	78.	55.
801008283	1.18	0.53	0.33	69.	14.	15.	33.	1563.	156.	0.00318	9.45	1304.	28.	50830.	18.	77.	56.
801008298	1.25	0.53	0.33	73.	14.	14.	33.	1576.	156.	0.00320	9.23	1344.	32.	49330.	34.	79.	60.
801008313	1.28	0.54	0.33	74.	14.	14.	33.	1554.	155.	0.00324	9.53	1375.	29.	49570.	26.	75.	56.
801008328	1.35	0.54	0.33	78.	14.	13.	33.	1538.	155.	0.00320	9.31	1400.	29.	51740.	22.	74.	53.
801008343	1.40	0.55	0.33	82.	14.	13.	33.	1535.	155.	0.00324	9.22	1412.	29.	51850.	19.	73.	52.
801008358	1.45	0.55	0.33	84.	14.	12.	32.	1544.	154.	0.00295	9.36	1421.	30.	52700.	22.	78.	54.
801008373	1.42	0.57	0.35	78.	14.	13.	33.	1530.	166.	0.00253	10.24	1372.	30.	57340.	15.	88.	56.
801008388	1.32	0.55	0.35	73.	14.	14.	34.	1481.	166.	0.00246	10.14	1346.	30.	58570.	13.	88.	55.
801008403	1.21	0.55	0.35	66.	14.	16.	34.	1459.	165.	0.00267	10.36	1355.	31.	56730.	17.	94.	61.
801008418	1.21	0.56	0.36	66.	14.	16.	34.	1446.	165.	0.00263	10.46	1336.	31.	57730.	16.	94.	60.
801008433	1.32	0.56	0.36	72.	14.	14.	34.	1423.	165.	0.00267	10.25	1366.	32.	54640.	18.	91.	61.
801008448	1.41	0.56	0.35	76.	13.	14.	34.	1455.	164.	0.00265	10.67	1393.	32.	55490.	15.	88.	58.
801008463	1.18	0.51	0.26	82.	16.	13.	29.	1440.	126.	0.00303	7.82	1455.	30.	36280.	9.	53.	54.
801008480	1.23	0.50	0.26	86.	16.	12.	29.	1442.	126.	0.00305	7.78	1473.	28.	36640.	8.	49.	50.
801008495	1.26	0.53	0.26	88.	16.	12.	28.	1445.	125.	0.00301	8.14	1486.	28.	36770.	8.	46.	46.
801008510	1.32	0.54	0.26	93.	17.	11.	27.	1441.	125.	0.00301	8.03	1498.	28.	36910.	7.	45.	45.
801008525	1.36	0.54	0.27	96.	17.	11.	27.	1435.	125.	0.00301	8.07	1485.	28.	36930.	8.	45.	45.

Table XIII-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801008540	1.43	0.55	0.26	100.	17.	10.	27.	1415.	125.	0.00301	7.96	1414.	29.	37010.	8.	47.	47.
801008555	1.41	0.56	0.26	99.	18.	10.	26.	1415.	125.	0.00303	8.11	1407.	29.	36970.	8.	40.	40.
801008569	1.36	0.56	0.26	95.	18.	11.	26.	1423.	125.	0.00301	8.18	1437.	29.	36700.	9.	44.	45.
801008584	1.30	0.56	0.26	92.	18.	11.	26.	1424.	125.	0.00301	8.20	1446.	29.	36910.	8.	46.	46.
801008599	1.27	0.56	0.26	90.	18.	12.	26.	1429.	125.	0.00303	7.92	1414.	30.	36980.	8.	50.	50.
801008614	1.22	0.56	0.26	87.	18.	12.	26.	1418.	125.	0.00309	7.84	1379.	31.	36850.	9.	53.	53.
801008629	1.16	0.55	0.26	82.	17.	13.	27.	1408.	125.	0.00303	8.04	1348.	32.	36610.	9.	59.	60.
801008644	1.17	0.53	0.23	95.	19.	11.	24.	1307.	107.	0.00347	6.79	1515.	32.	32370.	8.	47.	54.
801008659	1.20	0.54	0.23	98.	20.	11.	24.	1307.	107.	0.00345	6.96	1516.	31.	32270.	8.	43.	49.
801008674	1.25	0.57	0.23	102.	21.	10.	22.	1309.	106.	0.00362	7.07	1487.	31.	32170.	8.	39.	46.
801008689	1.31	0.56	0.23	107.	21.	10.	23.	1305.	106.	0.00355	6.88	1442.	30.	31860.	8.	36.	45.
801008704	1.36	0.59	0.23	111.	22.	9.	21.	1304.	106.	0.00349	6.88	1371.	30.	32030.	7.	38.	45.
801008719	1.43	0.57	0.23	117.	21.	9.	22.	1304.	106.	0.00353	6.78	1312.	30.	32320.	8.	39.	45.
801008734	1.43	0.56	0.23	118.	21.	9.	22.	1296.	106.	0.00351	6.87	1308.	30.	32090.	8.	37.	43.
801008749	1.35	0.56	0.23	112.	21.	9.	22.	1286.	106.	0.00358	6.91	1336.	31.	31880.	8.	37.	43.
801008764	1.30	0.55	0.23	109.	20.	9.	23.	1283.	105.	0.00360	6.81	1345.	31.	31970.	8.	36.	42.
801008779	1.25	0.56	0.23	105.	21.	10.	22.	1281.	106.	0.00358	6.76	1375.	32.	32160.	8.	36.	42.
801008794	1.21	0.55	0.23	101.	21.	10.	22.	1282.	106.	0.00358	6.64	1405.	33.	32150.	7.	37.	43.
801008809	1.17	0.54	0.23	98.	20.	11.	23.	1274.	106.	0.00358	6.52	1396.	34.	32090.	7.	41.	40.
801008824	1.48	0.61	0.24	119.	22.	9.	21.	1310.	105.	0.00539	6.81	1251.	30.	34930.	8.	100.	111.
801008839	1.46	0.59	0.24	119.	21.	9.	22.	1289.	105.	0.01033	6.77	1281.	31.	33420.	8.	87.	111.
801008854	1.48	0.61	0.24	120.	22.	9.	21.	1299.	105.	0.00556	6.69	1271.	31.	34110.	9.	76.	66.
801008869	1.45	0.59	0.24	120.	22.	9.	21.	1279.	105.	0.00523	6.62	1285.	31.	33420.	9.	56.	65.

Table XIII-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801008884	1.43	0.57	0.23	120.	21.	9.	22.	1287.	105.	0.00552	6.63	1270.	32.	33070.	10.	41.	40.
801008899	1.44	0.56	0.23	121.	21.	9.	22.	1297.	105.	0.00743	6.51	1257.	32.	33360.	10.	36.	40.

Table XIII-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801008193	0.0	99.86	3.	0.41	1.011	1.40	0.60
801008208	0.0	99.87	5.	0.41	0.977	1.35	0.60
801008223	0.0	99.87	5.	0.43	1.075	1.30	0.60
801008238	0.0	99.89	5.	0.43	1.076	1.25	0.60
801008253	0.0	99.89	6.	0.43	1.128	1.20	0.60
801008268	0.0	99.90	3.	0.55	1.110	1.15	0.60
801008283	0.0	99.92	5.	0.46	1.094	1.15	0.55
801008298	0.0	99.87	4.	0.46	1.060	1.20	0.55
801008313	0.0	99.90	3.	0.50	1.069	1.25	0.55
801008328	0.0	99.91	3.	0.51	1.098	1.30	0.55
801008343	0.0	99.91	3.	0.53	1.093	1.35	0.55
801008358	0.0	99.91	2.	0.52	1.110	1.40	0.55
801008373	0.0	99.92	3.	0.57	1.159	1.40	0.60
801008388	0.0	99.93	3.	0.63	1.181	1.30	0.60
801008403	0.0	99.92	3.	0.63	1.133	1.20	0.60
801008418	0.0	99.92	2.	0.79	1.144	1.20	0.55
801008433	0.0	99.91	2.	0.86	1.076	1.30	0.55
801008448	0.0	99.92	3.	0.85	1.104	1.40	0.55
801008463	0.0	99.91	0.	0.33	0.962	1.16	0.55
801008480	0.0	99.92	5.	0.32	0.977	1.20	0.55
801008495	0.0	99.92	0.	0.31	0.972	1.25	0.55
801008510	0.0	99.93	6.	0.30	0.977	1.30	0.55
801008525	0.0	99.92	14.	0.33	0.973	1.35	0.55
801008540	0.0	99.92	0.	0.37	0.990	1.40	0.55

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801008555	0.0	99.92	0.	0.38	0.985	1.40	0.60
801008569	0.0	99.92	8.	0.34	0.976	1.35	0.60
801008584	0.0	99.92	0.	0.39	0.984	1.30	0.60
801008599	0.0	99.92	0.	0.39	0.998	1.25	0.60
801008614	0.0	99.91	3.	0.40	0.992	1.20	0.60
801008629	0.0	99.91	5.	0.37	0.990	1.15	0.60
801008644	0.0	99.91	0.	0.35	1.003	1.15	0.55
801008659	0.0	99.91	0.	0.36	0.998	1.20	0.55
801008674	0.0	99.91	0.	0.37	0.987	1.25	0.55
801008689	0.0	99.91	9.	0.37	0.987	1.30	0.55
801008704	0.0	99.91	8.	0.35	0.977	1.35	0.55
801008719	0.0	99.91	0.	0.35	0.993	1.40	0.55
801008734	0.0	99.91	9.	0.34	0.982	1.40	0.60
801008749	0.0	99.91	8.	0.36	0.979	1.35	0.60
801008764	0.0	99.91	0.	0.35	0.988	1.30	0.60
801008779	0.0	99.91	0.	0.34	0.988	1.25	0.60
801008794	0.0	99.91	7.	0.34	0.987	1.20	0.60
801008809	0.0	99.91	5.	0.33	0.987	1.15	0.60
801008824	149.21	99.89	9.	0.30	0.997	1.40	0.60
801008839	180.01	99.89	0.	0.35	0.975	1.40	0.60
801008854	187.54	99.90	0.	0.35	0.981	1.40	0.60
801008869	233.46	99.90	0.	0.36	0.986	1.40	0.60
801008884	0.0	99.90	0.	0.35	0.999	1.40	0.60
801008899	0.0	99.91	0.	0.33	1.005	1.40	0.60

Table XIV.

RQL combustor performance data--RESID fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801009929	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	316.	MAX CONTINUOUS	0.0	635.	162.6	0.082	0.653	0.0	2.112
801009944	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	316.	MAX CONTINUOUS	0.0	639.	163.0	0.082	0.840	0.0	2.133
801009959	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	317.	MAX CONTINUOUS	0.0	641.	162.8	0.082	0.666	0.0	2.158
801009974	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	318.	MAX CONTINUOUS	0.0	646.	162.0	0.082	0.699	0.0	2.108
801009989	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	319.	MAX CONTINUOUS	0.0	648.	162.0	0.083	0.935	0.0	2.162
801009004	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	320.	MAX CONTINUOUS	0.0	649.	161.7	0.082	0.969	0.0	2.227
801009019	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	321.	MAX CONTINUOUS	0.0	651.	162.1	0.083	1.008	0.0	2.259
801009034	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	319.	MAX CONTINUOUS	0.0	653.	163.7	0.082	1.023	0.0	2.259
801009049	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	320.	MAX CONTINUOUS	0.0	654.	163.6	0.082	0.986	0.0	2.261
801009064	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	320.	MAX CONTINUOUS	0.0	655.	163.2	0.083	0.697	0.0	2.227
801009079	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	317.	MAX CONTINUOUS	0.0	654.	162.9	0.080	0.654	0.0	2.302
801009094	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	320.	MAX CONTINUOUS	0.0	655.	163.0	0.084	0.827	0.0	2.243
801009109	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	321.	MAX CONTINUOUS	0.0	657.	163.1	0.083	0.627	0.0	2.244
801009124	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	323.	MAX CONTINUOUS	0.0	658.	162.7	0.082	0.795	0.0	2.244
801009139	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	323.	MAX CONTINUOUS	0.0	660.	162.5	0.082	0.764	0.0	2.262
801009154	LINER I-E, NOZ AB-F	BP	11.08	0.72	17814.	320.	MAX CONTINUOUS	0.0	661.	162.7	0.082	0.762	0.0	2.239
801009169	LINER I-E, NOZ AB-F	BP	11.17	0.47	17880.	321.	MAX CONTINUOUS	0.0	661.	162.3	0.082	0.763	0.0	2.265
801009184	LINER I-E, NOZ AB-F	BP	11.20	0.38	17904.	324.	MAX CONTINUOUS	0.0	662.	162.1	0.082	0.761	0.0	2.260
801009199	LINER I-E, NOZ AB-F	BP	11.20	0.38	17904.	323.	MAX CONTINUOUS	0.0	664.	162.1	0.082	0.791	0.0	2.253
801009214	LINER I-E, NOZ AB-F	BP	11.17	0.49	17877.	322.	MAX CONTINUOUS	0.0	664.	162.1	0.078	0.789	0.0	2.290
801009229	LINER I-E, NOZ AB-F	BP	11.17	0.47	17880.	323.	MAX CONTINUOUS	0.0	665.	162.2	0.083	0.764	0.0	2.221
801009244	LINER I-E, NOZ AB-F	BP	11.09	0.72	17814.	320.	MAX CONTINUOUS	0.0	665.	162.7	0.083	0.772	0.0	2.232

Table XIV (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801009259	LINER I-E, NOZ AB-F	BP	11.08	0.72	17814.	320.	MAX CONTINUOUS	0.0	667.	162.8	0.082	0.814	0.0	2.275
801009274	LINER I-E, NOZ AB-F	BP	11.17	0.47	17879.	321.	MAX CONTINUOUS	0.0	667.	162.7	0.082	0.839	0.0	2.306
801009289	LINER I-E, NOZ AB-F	BP	11.20	0.38	17904.	322.	MAX CONTINUOUS	0.0	666.	162.6	0.082	0.843	0.0	2.310
801009304	LINER I-E, NOZ AB-F	BP	11.20	0.38	17904.	325.	MAX CONTINUOUS	0.0	668.	162.8	0.083	0.887	0.0	2.315
801009319	LINER I-E, NOZ AB-F	BP	11.17	0.47	17880.	324.	MAX CONTINUOUS	0.0	668.	162.8	0.083	0.894	0.0	2.265
801009334	LINER I-E, NOZ AB-F	BP	11.09	0.71	17815.	322.	MAX CONTINUOUS	0.0	668.	163.1	0.083	0.890	0.0	2.236
801009349	LINER I-E, NOZ AB-F	BP	11.09	0.72	17814.	324.	MAX CONTINUOUS	0.0	669.	163.2	0.083	0.976	0.0	2.264
801009364	LINER I-E, NOZ AB-F	BP	11.17	0.47	17879.	324.	MAX CONTINUOUS	0.0	670.	162.9	0.082	0.960	0.0	2.315
801009379	LINER I-E, NOZ AB-F	BP	11.20	0.38	17904.	326.	MAX CONTINUOUS	0.0	670.	163.0	0.082	0.981	0.0	2.278
801009394	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	327.	MAX RATED	0.0	672.	176.2	0.091	0.946	0.0	2.360
801009409	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	324.	MAX RATED	0.0	671.	175.8	0.092	1.010	0.0	2.426
801009424	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	325.	MAX RATED	0.0	671.	175.6	0.092	1.094	0.0	2.393
801009439	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	326.	MAX RATED	0.0	672.	175.4	0.092	1.067	0.0	2.397
801009454	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	328.	MAX RATED	0.0	672.	174.8	0.092	0.996	0.0	2.432
801009469	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	327.	MAX RATED	0.0	672.	174.7	0.092	0.949	0.0	2.346
801009484	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	310.	70% LOAD	0.0	567.	134.0	0.058	0.600	0.0	1.442
801009499	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	309.	70% LOAD	0.0	565.	133.8	0.058	0.630	0.0	1.531
801009514	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	310.	70% LOAD	0.0	565.	133.8	0.058	0.651	0.0	1.529
801009529	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	306.	70% LOAD	0.0	563.	134.0	0.059	0.660	0.0	1.520
801009544	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	309.	70% LOAD	0.0	563.	134.0	0.058	0.700	0.0	1.534
801009559	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	308.	70% LOAD	0.0	562.	134.1	0.059	0.730	0.0	1.569
801009574	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	310.	70% LOAD	0.0	562.	134.0	0.057	0.738	0.0	1.597
801009589	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	309.	70% LOAD	0.0	562.	134.3	0.058	0.742	0.0	1.601
801009604	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	310.	70% LOAD	0.0	561.	134.1	0.057	0.736	0.0	1.615

Table XIV (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801009619	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	309.	70% LOAD	0.0	560.	134.0	0.059	0.714	0.0	1.639
801009634	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	310.	70% LOAD	0.0	560.	133.9	0.058	0.677	0.0	1.666
801009649	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	309.	70% LOAD	0.0	560.	134.2	0.059	0.653	0.0	1.608
801009667	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	310.	70% LOAD	0.0	559.	134.4	0.059	0.632	0.0	1.579
801009682	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	309.	70% LOAD	0.0	558.	134.2	0.059	0.610	0.0	1.613
801009697	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	312.	50% LOAD	0.0	546.	113.4	0.045	0.457	0.0	1.154
801009712	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	311.	50% LOAD	0.0	544.	113.4	0.046	0.475	0.0	1.130
801009727	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	312.	50% LOAD	0.0	543.	113.3	0.045	0.489	0.0	1.149
801009743	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	311.	50% LOAD	0.0	542.	113.3	0.045	0.507	0.0	1.158
801009758	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	312.	50% LOAD	0.0	541.	113.3	0.045	0.531	0.0	1.163
801009773	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	313.	50% LOAD	0.0	541.	113.1	0.044	0.545	0.0	1.204
801009788	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	312.	50% LOAD	0.0	540.	113.3	0.045	0.562	0.0	1.217
801009803	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	311.	50% LOAD	0.0	537.	113.3	0.045	0.539	0.0	1.211
801009818	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	311.	50% LOAD	0.0	537.	113.3	0.045	0.501	0.0	1.178
801009833	LINER I-E, NOZ AB-F	B	11.24	0.27	17933.	314.	50% LOAD	0.0	536.	113.4	0.045	0.468	0.0	1.155

Table XIV-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801009929	1.36	0.55	0.32	82.	15.	13.	31.	1516.	153.	0.00297	10.03	1644.	29.	45160.	9.	65.	53.
801009944	1.38	0.54	0.31	83.	15.	12.	32.	1532.	153.	0.00295	9.76	1626.	28.	43580.	6.	65.	55.
801009959	1.34	0.54	0.31	81.	14.	13.	32.	1530.	153.	0.00297	9.58	1645.	28.	43540.	7.	65.	55.
801009974	1.29	0.55	0.32	77.	15.	13.	32.	1530.	152.	0.00297	9.72	1672.	28.	44230.	6.	68.	57.
801009989	1.25	0.54	0.32	74.	14.	14.	33.	1521.	152.	0.00297	9.73	1659.	28.	45440.	5.	70.	57.
801009004	1.20	0.52	0.32	71.	14.	15.	34.	1522.	152.	0.00295	9.62	1670.	28.	45180.	5.	76.	62.
801009019	1.15	0.51	0.32	68.	14.	15.	34.	1492.	153.	0.00276	9.55	1643.	28.	45540.	5.	85.	68.
801009034	1.13	0.51	0.32	68.	14.	15.	34.	1474.	154.	0.00274	9.77	1650.	28.	49020.	4.	95.	71.
801009049	1.17	0.51	0.32	70.	14.	15.	34.	1466.	154.	0.00278	9.92	1661.	28.	50630.	1.	89.	65.
801009064	1.30	0.52	0.32	77.	14.	13.	34.	1546.	154.	0.00271	9.66	1678.	28.	47230.	4.	68.	53.
801009079	1.32	0.49	0.31	81.	13.	13.	35.	1528.	154.	0.00265	9.43	1673.	28.	46280.	5.	62.	49.
801009094	1.43	0.53	0.33	84.	14.	12.	34.	1532.	153.	0.00269	9.59	1648.	29.	42450.	3.	56.	50.
801009109	1.41	0.52	0.32	84.	14.	12.	34.	1532.	153.	0.00286	9.60	1619.	29.	43640.	4.	61.	51.
801009124	1.45	0.52	0.32	87.	14.	12.	34.	1526.	153.	0.00269	9.77	1596.	30.	43040.	4.	62.	53.
801009139	1.52	0.51	0.32	90.	13.	11.	34.	1496.	153.	0.00278	9.99	1534.	32.	42250.	5.	65.	57.
801009154	1.57	0.53	0.33	91.	14.	11.	34.	1501.	153.	0.00276	9.92	1482.	31.	44740.	3.	90.	74.
801009169	1.54	0.52	0.32	90.	13.	11.	34.	1485.	152.	0.00276	9.98	1509.	32.	42820.	4.	68.	58.
801009184	1.54	0.52	0.32	90.	13.	11.	34.	1491.	152.	0.00280	9.95	1518.	31.	43900.	5.	71.	60.
801009199	1.48	0.52	0.32	86.	13.	12.	34.	1499.	152.	0.00284	9.82	1597.	30.	41600.	4.	63.	55.
801009214	1.41	0.49	0.30	87.	13.	12.	35.	1487.	152.	0.00282	9.76	1608.	30.	44130.	4.	69.	57.
801009229	1.50	0.53	0.33	87.	14.	12.	34.	1514.	153.	0.00274	9.64	1606.	31.	41520.	4.	59.	52.
801009244	1.56	0.54	0.34	89.	14.	12.	34.	1525.	153.	0.00271	9.33	1575.	29.	43190.	3.	77.	65.
801009259	1.47	0.53	0.33	84.	13.	12.	35.	1505.	153.	0.00280	9.41	1598.	29.	46120.	4.	71.	57.

Table XIV-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801009274	1.39	0.51	0.32	81.	13.	13.	35.	1480.	153.	0.00271	10.00	1619.	29.	43900.	3.	65.	54.
801009289	1.38	0.50	0.32	81.	13.	13.	35.	1483.	152.	0.00276	10.09	1641.	29.	43900.	3.	60.	50.
801009304	1.32	0.51	0.32	77.	13.	13.	35.	1484.	153.	0.00269	9.60	1693.	28.	43200.	3.	63.	53.
801009319	1.32	0.52	0.33	76.	13.	14.	35.	1486.	153.	0.00274	9.75	1709.	28.	44380.	3.	63.	53.
801009334	1.35	0.54	0.34	77.	14.	13.	34.	1514.	153.	0.00271	9.65	1705.	28.	48180.	4.	70.	53.
801009349	1.23	0.53	0.34	70.	13.	15.	35.	1373.	153.	0.00280	9.82	1689.	28.	54920.	5.	81.	54.
801009364	1.19	0.51	0.33	70.	13.	15.	35.	1350.	153.	0.00263	9.91	1685.	29.	52300.	4.	86.	60.
801009379	1.19	0.51	0.33	69.	13.	15.	35.	1352.	153.	0.00269	9.94	1691.	29.	53230.	4.	85.	59.
801009394	1.36	0.55	0.34	78.	14.	13.	33.	1504.	166.	0.00257	10.51	1665.	28.	48450.	4.	68.	51.
801009409	1.28	0.53	0.34	73.	13.	14.	34.	1399.	165.	0.00248	10.29	1699.	29.	54130.	4.	78.	53.
801009424	1.18	0.54	0.35	67.	14.	15.	34.	1425.	165.	0.00253	10.31	1691.	28.	50380.	4.	93.	67.
801009439	1.19	0.54	0.35	67.	14.	15.	34.	1424.	165.	0.00253	10.19	1703.	28.	52000.	4.	92.	65.
801009454	1.30	0.53	0.34	73.	13.	14.	35.	1391.	165.	0.00259	10.08	1735.	29.	51140.	5.	73.	52.
801009469	1.36	0.54	0.34	77.	14.	13.	34.	1415.	164.	0.00253	10.65	1728.	30.	52100.	4.	73.	51.
801009484	1.36	0.57	0.25	103.	19.	10.	24.	1356.	126.	0.00345	7.87	1522.	32.	30490.	3.	34.	42.
801009499	1.29	0.53	0.25	98.	18.	11.	26.	1336.	126.	0.00337	8.04	1567.	33.	31350.	3.	38.	45.
801009514	1.25	0.53	0.25	95.	18.	11.	26.	1342.	126.	0.00337	7.98	1594.	33.	31040.	3.	42.	51.
801009529	1.22	0.54	0.25	91.	18.	11.	26.	1365.	126.	0.00332	7.98	1641.	31.	32440.	6.	50.	57.
801009544	1.17	0.53	0.25	88.	18.	12.	26.	1358.	126.	0.00328	7.85	1637.	32.	32310.	5.	55.	63.
801009559	1.12	0.52	0.25	84.	17.	12.	27.	1365.	126.	0.00330	7.98	1594.	34.	31150.	4.	73.	87.
801009574	1.08	0.50	0.24	84.	17.	12.	27.	1333.	126.	0.00330	7.98	1575.	34.	31540.	4.	69.	81.
801009589	1.11	0.51	0.25	84.	17.	12.	27.	1362.	126.	0.00328	8.03	1621.	33.	31940.	4.	65.	75.
801009604	1.09	0.50	0.25	84.	17.	12.	27.	1340.	126.	0.00322	7.92	1608.	34.	30420.	5.	70.	65.

Table XIV-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801009619	1.16	0.50	0.25	87.	17.	12.	28.	1370.	126.	0.00330	8.09	1654.	33.	32910.	3.	56.	63.
801009634	1.20	0.49	0.25	92.	17.	11.	28.	1357.	126.	0.00330	7.90	1666.	33.	32570.	3.	48.	55.
801009649	1.26	0.51	0.25	95.	17.	11.	27.	1362.	126.	0.00334	7.92	1650.	33.	31460.	4.	40.	47.
801009667	1.31	0.53	0.26	99.	18.	10.	26.	1373.	126.	0.00324	7.59	1592.	33.	32390.	4.	37.	42.
801009682	1.36	0.51	0.26	102.	17.	10.	27.	1366.	126.	0.00324	8.08	1511.	36.	31860.	4.	37.	43.
801009697	1.39	0.55	0.22	117.	21.	9.	23.	1285.	107.	0.00376	6.81	1484.	34.	31630.	4.	51.	60.
801009712	1.35	0.57	0.23	112.	21.	9.	22.	1282.	107.	0.00376	6.82	1518.	36.	30310.	4.	40.	49.
801009727	1.30	0.55	0.22	109.	21.	9.	22.	1272.	107.	0.00383	6.72	1553.	35.	30800.	4.	42.	51.
801009743	1.26	0.55	0.22	105.	20.	10.	23.	1270.	107.	0.00389	6.62	1600.	36.	29520.	13.	37.	47.
801009758	1.19	0.54	0.22	101.	20.	10.	23.	1270.	107.	0.00381	6.68	1627.	35.	31030.	3.	43.	52.
801009773	1.13	0.51	0.21	98.	20.	11.	23.	1252.	107.	0.00374	6.50	1664.	36.	30130.	3.	48.	59.
801009788	1.12	0.52	0.22	95.	20.	11.	24.	1264.	106.	0.00383	6.90	1685.	37.	29610.	3.	50.	63.
801009803	1.18	0.52	0.22	99.	20.	10.	24.	1272.	106.	0.00383	6.88	1688.	37.	29170.	4.	43.	55.
801009818	1.26	0.54	0.22	107.	20.	10.	23.	1274.	106.	0.00376	7.00	1589.	37.	30560.	4.	39.	47.
801009833	1.35	0.55	0.22	115.	21.	9.	22.	1279.	106.	0.00381	7.07	1463.	34.	30090.	5.	42.	52.

Table XIV-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801009929	141.85	99.93	3.	0.52	0.956	1.40	0.60
801009944	147.21	99.93	0.	0.52	0.928	1.40	0.60
801009959	148.44	99.93	3.	0.51	0.931	1.35	0.60
801009974	150.34	99.93	2.	0.48	0.929	1.30	0.60
801009989	150.60	99.94	2.	0.48	0.949	1.25	0.60
801009004	164.33	99.93	0.	0.45	0.946	1.20	0.60
801009019	178.92	99.93	3.	0.48	0.945	1.15	0.60
801009034	185.46	99.93	0.	0.54	1.016	1.15	0.55
801009049	168.39	99.94	3.	0.53	1.051	1.20	0.55
801009064	138.54	99.94	0.	0.43	0.985	1.25	0.55
801009079	135.02	99.94	0.	0.44	1.007	1.30	0.55
801009094	129.89	99.94	4.	0.46	0.866	1.35	0.55
801009109	134.52	99.94	0.	0.45	0.906	1.40	0.55
801009124	138.78	99.93	8.	0.49	0.900	1.45	0.55
801009139	149.55	99.93	8.	0.48	0.886	1.50	0.55
801009154	71.12	99.93	0.	0.49	0.904	1.50	0.55
801009169	87.36	99.93	0.	0.50	0.887	1.50	0.55
801009184	111.43	99.93	0.	0.48	0.912	1.50	0.55
801009199	102.92	99.93	0.	0.49	0.659	1.45	0.55
801009214	89.11	99.93	0.	0.48	0.970	1.45	0.55
801009229	77.36	99.93	0.	0.50	0.842	1.45	0.55
801009244	62.03	99.93	0.	0.52	0.858	1.45	0.55
801009259	53.68	99.94	0.	0.50	0.920	1.40	0.55

Table XIV-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801009274	81.65	99.94	0.	0.52	0.911	1.40	0.55
801009289	93.82	99.94	0.	0.52	0.917	1.40	0.55
801009304	98.71	99.94	0.	0.53	0.890	1.30	0.55
801009319	77.40	99.94	0.	0.53	0.898	1.30	0.55
801009334	49.94	99.94	0.	0.51	0.946	1.30	0.55
801009349	50.81	99.94	0.	0.79	1.083	1.20	0.55
801009364	89.29	99.94	0.	0.79	1.076	1.20	0.55
801009379	106.63	99.94	0.	0.78	1.085	1.20	0.55
801009394	126.64	99.94	0.	0.55	0.950	1.40	0.60
801009409	129.19	99.94	0.	0.88	1.058	1.30	0.60
801009424	164.34	99.94	0.	0.79	0.977	1.20	0.60
801009439	157.32	99.94	3.	0.88	1.004	1.20	0.55
801009454	129.19	99.94	0.	0.95	1.001	1.30	0.55
801009469	125.26	99.94	0.	0.83	1.017	1.40	0.55
801009484	140.04	99.92	9.	0.32	0.807	1.40	0.60
801009499	153.85	99.92	0.	0.34	0.842	1.35	0.60
801009514	170.93	99.92	0.	0.35	0.831	1.30	0.60
801009529	190.00	99.91	9.	0.31	0.851	1.25	0.60
801009544	211.39	99.91	0.	0.32	0.858	1.20	0.60
801009559	288.59	99.90	0.	0.33	0.815	1.15	0.60
801009574	278.41	99.90	0.	0.33	0.858	1.15	0.55
801009589	250.53	99.90	7.	0.32	0.846	1.15	0.55
801009604	290.21	99.89	0.	0.34	0.823	1.15	0.55

Table XIV-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801009619	207.42	99.92	0.	0.44	0.861	1.20	0.55
801009634	186.84	99.92	0.	0.42	0.875	1.25	0.55
801009649	154.61	99.92	0.	0.35	0.826	1.30	0.55
801009667	136.00	99.92	7.	0.32	0.834	1.35	0.55
801009682	141.95	99.91	0.	0.29	0.832	1.40	0.55
801009697	224.58	99.91	10.	0.32	0.943	1.40	0.60
801009712	182.06	99.91	0.	0.33	0.889	1.35	0.60
801009727	190.19	99.91	0.	0.33	0.915	1.30	0.60
801009743	174.97	99.88	9.	0.35	0.878	1.25	0.60
801009758	196.30	99.91	0.	0.33	0.932	1.20	0.60
801009773	231.34	99.91	0.	0.34	0.934	1.15	0.60
801009788	237.88	99.90	0.	0.31	0.889	1.15	0.55
801009803	205.51	99.90	0.	0.31	0.868	1.20	0.55
801009818	179.14	99.91	10.	0.31	0.917	1.30	0.55
801009833	195.15	99.91	0.	0.32	0.897	1.40	0.55

Table XV.

RQL combustor performance data--SRC-II fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801015117	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	170.	MAX CONTINUOUS	0.0	645.	162.6	0.082	0.790	0.0	2.047
801015133	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	169.	MAX CONTINUOUS	0.0	649.	162.6	0.083	0.785	0.0	2.040
801015148	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	169.	MAX CONTINUOUS	0.0	652.	162.6	0.082	0.776	0.0	2.067
801015163	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	170.	MAX CONTINUOUS	0.0	653.	162.6	0.082	0.803	0.0	2.076
801015178	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	173.	MAX CONTINUOUS	0.0	655.	162.6	0.083	0.799	0.0	2.088
801015193	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	171.	MAX CONTINUOUS	0.0	658.	162.1	0.082	0.803	0.0	2.087
801015208	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	168.	MAX CONTINUOUS	0.0	658.	162.0	0.082	0.838	0.0	2.076
801015223	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	171.	MAX CONTINUOUS	0.0	659.	162.1	0.082	0.828	0.0	2.024
801015238	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	167.	MAX CONTINUOUS	0.0	659.	162.1	0.083	0.831	0.0	2.053
801015253	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	172.	MAX CONTINUOUS	0.0	661.	161.9	0.082	0.872	0.0	2.120
801015268	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	169.	MAX CONTINUOUS	0.0	664.	163.9	0.083	0.875	0.0	2.132
801015283	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	170.	MAX CONTINUOUS	0.0	664.	163.8	0.082	0.874	0.0	2.151
801015298	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	172.	MAX CONTINUOUS	0.0	665.	163.8	0.083	0.913	0.0	2.126
801015313	LINER I-E, NOZ AB-F	CP	8.78	1.05	17309.	170.	MAX CONTINUOUS	0.0	665.	163.9	0.082	0.912	0.0	2.127
801015328	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	173.	MAX CONTINUOUS	0.0	666.	164.0	0.082	0.912	0.0	2.102
801015343	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	173.	MAX CONTINUOUS	0.0	667.	163.8	0.082	0.951	0.0	2.109
801015358	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	174.	MAX CONTINUOUS	0.0	668.	163.8	0.083	0.957	0.0	2.132
801015373	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	174.	MAX CONTINUOUS	0.0	668.	163.7	0.082	0.962	0.0	2.146
801015388	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	174.	MAX CONTINUOUS	0.0	671.	163.4	0.082	0.950	0.0	2.172
801015403	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	172.	MAX CONTINUOUS	0.0	673.	163.4	0.083	0.946	0.0	2.144
801015418	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	176.	MAX CONTINUOUS	0.0	673.	163.7	0.083	0.943	0.0	2.115
801015433	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	176.	MAX CONTINUOUS	0.0	673.	163.6	0.083	0.898	0.0	2.102
801015448	LINER I-E, NOZ AB-F	CP	8.78	1.05	17309.	175.	MAX CONTINUOUS	0.0	673.	163.4	0.082	0.908	0.0	2.171

Table XV (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	W FUEL P (LB/S)	PINLET (PSIA)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801015463	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	MAX CONTINUOUS	0.0	675.	163.3	0.083	0.900	0.0	2.166
801015478	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	174.	MAX CONTINUOUS	0.0	676.	163.3	0.082	0.864	0.0	2.120
801015493	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	176.	MAX CONTINUOUS	0.0	676.	163.4	0.082	0.853	0.0	2.094
801015508	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	174.	MAX CONTINUOUS	0.0	677.	163.5	0.082	0.868	0.0	2.100
801015523	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	173.	MAX CONTINUOUS	0.0	677.	163.2	0.082	0.825	0.0	2.114
801015538	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	177.	MAX CONTINUOUS	0.0	678.	163.2	0.082	0.838	0.0	2.119
801015553	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	MAX CONTINUOUS	0.0	677.	163.0	0.082	0.835	0.0	2.123
801015572	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	MAX CONTINUOUS	0.0	679.	163.1	0.082	0.802	0.0	2.088
801015587	LINER I-E, NOZ AB-F	CP	8.78	1.05	17309.	172.	MAX CONTINUOUS	0.0	677.	163.1	0.082	0.793	0.0	2.118
801015602	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	174.	MAX CONTINUOUS	0.0	678.	163.3	0.083	0.799	0.0	2.075
801015617	LINER I-E, NOZ AB-F	CP	8.76	1.20	17275.	175.	MAX CONTINUOUS	0.0	677.	163.6	0.082	0.776	0.0	2.105
801015632	LINER I-E, NOZ AB-F	CP	8.78	1.05	17310.	177.	MAX CONTINUOUS	0.0	678.	163.2	0.082	0.788	0.0	2.124
801015647	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	MAX CONTINUOUS	0.0	678.	163.6	0.082	0.774	0.0	2.147
801015662	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	176.	MAX CONTINUOUS	0.0	679.	163.7	0.082	0.780	0.0	2.074
801015677	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	177.	MAX CONTINUOUS	0.0	679.	163.8	0.082	0.737	0.0	2.095
801015692	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	MAX CONTINUOUS	0.0	676.	164.0	0.082	0.668	0.0	2.073
801015707	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	172.	MAX CONTINUOUS	0.0	677.	164.3	0.082	0.637	0.0	2.145
801015722	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	174.	MAX RATED	0.0	680.	176.7	0.092	0.891	0.0	2.310
801015738	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	172.	MAX RATED	0.0	680.	176.8	0.091	0.954	0.0	2.370
801015753	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	171.	MAX RATED	0.0	681.	176.9	0.092	1.038	0.0	2.436
801015768	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	MAX RATED	0.0	680.	177.2	0.092	1.032	0.0	2.461
801015783	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	171.	MAX RATED	0.0	680.	176.1	0.091	0.954	0.0	2.427
801015798	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	172.	MAX RATED	0.0	681.	176.0	0.092	0.868	0.0	2.368

Table XV (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801015813	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	173.	70% LOAD	0.0	604.	133.3	0.059	0.556	0.0	1.358
801015828	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	175.	70% LOAD	0.0	595.	133.1	0.059	0.650	0.0	1.450
801015843	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	172.	50% LOAD	0.0	548.	113.8	0.046	0.436	0.0	0.989
801015858	LINER I-E, NOZ AB-F	C	8.81	0.88	17349.	167.	50% LOAD	0.0	534.	114.1	0.046	0.520	0.0	1.151

Table XV-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801015117	1.41	0.54	0.31	90.	15.	12.	30.	1590.	153.	0.00265	9.82	1476.	30.	45560.	9.	66.	54.
801015133	1.45	0.56	0.31	90.	15.	11.	30.	1607.	153.	0.00240	9.73	1490.	28.	47200.	7.	77.	66.
801015148	1.47	0.55	0.31	91.	15.	11.	31.	1615.	153.	0.00204	9.58	1491.	28.	47600.	7.	83.	63.
801015163	1.42	0.55	0.32	88.	15.	12.	31.	1614.	153.	0.00177	9.61	1480.	28.	47290.	7.	71.	55.
801015178	1.42	0.54	0.31	88.	15.	12.	31.	1602.	153.	0.00211	9.53	1526.	28.	46850.	7.	66.	53.
801015193	1.39	0.54	0.31	87.	15.	12.	31.	1595.	152.	0.00200	9.67	1541.	29.	45590.	7.	63.	50.
801015208	1.33	0.54	0.31	83.	15.	12.	31.	1597.	152.	0.00221	9.69	1541.	29.	45390.	6.	63.	50.
801015223	1.37	0.56	0.32	84.	15.	12.	31.	1615.	153.	0.00213	9.46	1546.	28.	46780.	6.	65.	50.
801015238	1.38	0.56	0.32	84.	15.	12.	31.	1627.	153.	0.00142	9.54	1536.	28.	47680.	6.	68.	51.
801015253	1.31	0.54	0.32	80.	14.	13.	32.	1615.	152.	0.00148	9.76	1559.	28.	47880.	6.	72.	54.
801015268	1.30	0.53	0.31	80.	14.	13.	32.	1606.	154.	0.00186	9.73	1583.	28.	45430.	5.	70.	56.
801015283	1.28	0.52	0.30	80.	14.	13.	32.	1590.	154.	0.00148	9.71	1577.	28.	45090.	6.	69.	55.
801015298	1.23	0.53	0.31	77.	14.	13.	32.	1598.	154.	0.00171	9.73	1538.	28.	45140.	6.	79.	63.
801015313	1.24	0.53	0.31	77.	14.	13.	32.	1608.	154.	0.00177	9.72	1549.	28.	46380.	5.	82.	64.
801015328	1.26	0.54	0.32	77.	15.	13.	32.	1612.	154.	0.00171	9.72	1544.	28.	46810.	6.	85.	66.
801015343	1.21	0.54	0.32	73.	15.	14.	32.	1619.	154.	0.00175	9.71	1495.	28.	46540.	6.	92.	71.
801015358	1.19	0.53	0.31	73.	14.	14.	32.	1607.	154.	0.00152	9.85	1516.	28.	46230.	6.	101.	79.
801015373	1.16	0.52	0.30	72.	14.	14.	32.	1592.	154.	0.00154	9.96	1505.	29.	45090.	6.	103.	82.
801015388	1.18	0.51	0.30	73.	14.	14.	33.	1592.	154.	0.00181	9.77	1516.	29.	47530.	7.	104.	79.
801015403	1.20	0.53	0.31	73.	14.	14.	33.	1605.	154.	0.00183	9.68	1530.	29.	49070.	7.	102.	75.
801015418	1.22	0.54	0.32	73.	14.	14.	32.	1620.	154.	0.00181	9.62	1541.	28.	50210.	7.	100.	72.
801015433	1.28	0.55	0.32	77.	15.	13.	32.	1615.	154.	0.00181	9.54	1571.	28.	49170.	7.	67.	64.
801015448	1.24	0.52	0.31	76.	14.	14.	33.	1603.	154.	0.00186	9.75	1549.	28.	47450.	7.	67.	66.

Table XV-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801015463	1.24	0.52	0.31	77.	14.	13.	33.	1605.	154.	0.00181	9.59	1548.	28.	47170.	7.	88.	67.
801015478	1.29	0.53	0.31	80.	14.	13.	32.	1604.	154.	0.00177	9.62	1573.	28.	46610.	6.	75.	58.
801015493	1.33	0.54	0.31	81.	15.	13.	32.	1622.	154.	0.00181	9.38	1573.	28.	47900.	6.	75.	56.
801015508	1.32	0.55	0.31	80.	14.	13.	32.	1629.	154.	0.00183	9.70	1574.	28.	49050.	6.	80.	59.
801015523	1.39	0.54	0.31	84.	14.	12.	32.	1632.	154.	0.00183	9.48	1585.	28.	49650.	6.	75.	55.
801015538	1.35	0.53	0.31	82.	14.	13.	32.	1620.	153.	0.00181	9.79	1563.	28.	47940.	6.	72.	55.
801015553	1.34	0.52	0.30	83.	14.	13.	32.	1610.	153.	0.00181	9.74	1576.	28.	47490.	6.	70.	53.
801015572	1.39	0.54	0.30	86.	14.	12.	32.	1594.	153.	0.00181	9.69	1627.	28.	47980.	6.	70.	53.
801015587	1.43	0.53	0.31	87.	14.	12.	32.	1611.	154.	0.00179	9.44	1633.	28.	48710.	6.	77.	57.
801015602	1.44	0.55	0.32	87.	15.	12.	32.	1617.	154.	0.00179	9.60	1598.	28.	48300.	6.	76.	58.
801015617	1.47	0.54	0.31	89.	14.	12.	32.	1609.	154.	0.00173	9.62	1527.	28.	48560.	5.	86.	64.
801015632	1.44	0.53	0.31	88.	14.	12.	32.	1595.	153.	0.00179	10.15	1506.	28.	47270.	5.	75.	57.
801015647	1.44	0.52	0.30	89.	14.	12.	33.	1589.	154.	0.00171	9.79	1520.	28.	46630.	6.	70.	54.
801015662	1.43	0.54	0.31	89.	15.	12.	32.	1594.	154.	0.00146	9.92	1547.	29.	48030.	6.	75.	56.
801015677	1.51	0.53	0.30	94.	15.	11.	32.	1600.	154.	0.00158	9.73	1536.	29.	47040.	6.	84.	64.
801015692	1.66	0.54	0.31	105.	15.	10.	31.	1596.	155.	0.00173	9.36	1392.	30.	46980.	6.	119.	91.
801015707	1.75	0.52	0.30	110.	14.	9.	33.	1602.	155.	0.00181	9.66	1273.	30.	45140.	6.	149.	119.
801015722	1.39	0.54	0.32	84.	14.	12.	33.	1616.	166.	0.00246	10.67	1591.	29.	52210.	8.	80.	56.
801015738	1.30	0.52	0.32	78.	14.	13.	33.	1611.	166.	0.00234	10.56	1574.	29.	52080.	7.	80.	56.
801015753	1.20	0.51	0.31	72.	13.	14.	34.	1631.	166.	0.00267	10.58	1503.	29.	51730.	7.	98.	69.
801015768	1.20	0.50	0.32	72.	13.	14.	35.	1563.	167.	0.00225	10.45	1513.	30.	52560.	6.	99.	68.
801015783	1.30	0.51	0.32	78.	13.	13.	34.	1600.	166.	0.00230	10.58	1592.	29.	52350.	6.	83.	57.
801015798	1.40	0.53	0.32	84.	14.	12.	34.	1634.	165.	0.00219	10.62	1542.	29.	50480.	6.	73.	53.

Table XV-A (Cont)

READING NUMBER	PRIMARY (FICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PPIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801015813	1.44	0.59	0.25	109.	26.	9.	24.	1413.	125.	0.00339	8.01	1443.	28.	35790.	5.	70.	72.
801015828	1.23	0.55	0.25	93.	18.	11.	25.	1401.	125.	0.00374	7.92	1511.	30.	36200.	5.	64.	66.
801015843	1.44	0.63	0.22	125.	24.	8.	19.	1272.	107.	0.00355	6.99	1342.	29.	29780.	6.	83.	104.
801015858	1.20	0.54	0.21	106.	21.	10.	22.	1240.	107.	0.00442	6.58	1508.	33.	30360.	5.	45.	57.

Table XV-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801015117	43.46	99.92	3.	0.36	0.932	1.40	0.60
801015133	39.70	99.93	0.	0.35	0.944	1.40	0.60
801015148	36.87	99.93	0.	0.34	0.948	1.40	0.60
801015163	31.47	99.93	0.	0.33	0.937	1.35	0.60
801015178	35.08	99.93	0.	0.32	0.936	1.35	0.60
801015193	40.49	99.93	3.	0.35	0.932	1.35	0.60
801015208	40.89	99.93	0.	0.33	0.927	1.30	0.60
801015223	33.18	99.93	0.	0.34	0.925	1.30	0.60
801015238	29.38	99.93	0.	0.32	0.937	1.30	0.60
801015253	30.94	99.93	0.	0.37	0.947	1.25	0.60
801015268	37.27	99.93	0.	0.38	0.914	1.25	0.60
801015283	44.83	99.93	0.	0.37	0.928	1.25	0.60
801015298	51.12	99.93	0.	0.37	0.920	1.20	0.60
801015313	43.03	99.93	0.	0.37	0.936	1.20	0.60
801015328	37.74	99.93	0.	0.36	0.925	1.20	0.60
801015343	40.99	99.93	0.	0.39	0.920	1.15	0.60
801015358	52.65	99.92	0.	0.39	0.930	1.15	0.60
801015373	66.85	99.92	3.	0.38	0.926	1.15	0.60
801015388	64.48	99.92	3.	0.37	0.981	1.15	0.55
801015403	50.35	99.92	0.	0.37	0.987	1.15	0.55
801015418	41.35	99.93	0.	0.36	0.991	1.15	0.55
801015433	36.63	99.93	0.	0.35	0.963	1.20	0.55
801015448	44.87	99.93	0.	0.35	0.967	1.20	0.55
801015463	54.50	99.93	3.	0.35	0.966	1.20	0.55
801015478	47.06	99.93	0.	0.35	0.954	1.25	0.55

Table XV-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801015493	37.61	99.93	0.	0.36	0.958	1.25	0.55
801015508	33.97	99.93	0.	0.37	0.975	1.25	0.55
801015523	31.61	99.94	0.	0.37	0.986	1.30	0.55
801015538	36.72	99.93	0.	0.36	0.969	1.30	0.55
801015553	43.08	99.93	0.	0.36	0.976	1.30	0.55
801015572	43.12	99.93	0.	0.39	0.986	1.35	0.55
801015587	38.86	99.93	0.	0.39	0.993	1.35	0.55
801015602	33.64	99.93	0.	0.40	0.957	1.35	0.55
801015617	37.07	99.93	0.	0.38	0.971	1.40	0.55
801015632	38.71	99.93	0.	0.38	0.962	1.40	0.55
801015647	44.48	99.93	3.	0.37	0.968	1.40	0.55
801015662	45.72	99.93	0.	0.38	0.982	1.40	0.55
801015677	52.17	99.93	0.	0.39	0.966	1.50	0.55
801015692	74.10	99.91	3.	0.44	0.959	1.60	0.55
801015707	96.96	99.90	3.	0.46	0.925	1.70	0.55
801015722	43.92	99.93	3.	0.41	1.031	1.40	0.60
801015738	44.18	99.93	0.	0.46	1.033	1.30	0.60
801015753	54.61	99.93	0.	0.42	1.028	1.20	0.60
801015768	53.55	99.93	0.	0.62	1.037	1.20	0.55
801015783	44.64	99.93	0.	0.53	1.025	1.30	0.55
801015798	40.54	99.94	0.	0.51	0.980	1.40	0.55
801015813	71.87	99.91	0.	0.32	0.894	1.40	0.60
801015828	65.04	99.92	0.	0.39	0.898	1.20	0.60
801015843	118.39	99.89	0.	0.34	0.854	1.40	0.60
801015858	66.03	99.90	0.	0.33	0.891	1.20	0.60

Table XVI.

RQL combustor parametric: lean zone equivalence ratio--ERBS fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801113133	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	627.	162.8	0.083	0.847	0.0	2.465
801113148	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	674.	163.1	0.083	0.774	0.0	2.438
801113163	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	660.	163.2	0.076	0.789	0.0	2.541
801120161	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	654.	164.2	0.083	0.778	0.0	2.345
801120176	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	670.	164.6	0.081	0.768	0.0	2.417
801120191	LINER I-E, NOZ AB-G	AP	12.62	0.57	18164.	--	MAX CONTINUOUS	0.0	669.	164.6	0.079	0.788	0.0	2.414
801120206	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	667.	164.5	0.079	0.763	0.0	2.420
801120221	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	665.	164.9	0.083	0.784	0.0	2.363
801120236	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	663.	163.1	0.083	0.800	0.0	2.347
801120251	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	662.	163.1	0.081	0.810	0.0	2.312
801120266	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	662.	163.3	0.079	0.806	0.0	2.318
801120281	LINER I-E, NOZ AB-G	AP	12.54	0.76	18110.	--	MAX CONTINUOUS	0.0	663.	167.2	0.078	0.828	0.0	2.365
801120296	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	663.	165.7	0.083	0.899	0.0	2.400
801120311	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	666.	167.5	0.081	0.917	0.0	2.462
801120326	LINER I-E, NOZ AB-G	AP	12.62	0.57	18164.	--	MAX CONTINUOUS	0.0	665.	164.8	0.079	0.894	0.0	2.452
801120341	LINER I-E, NOZ AB-G	AP	12.54	0.76	18110.	--	MAX CONTINUOUS	0.0	666.	164.4	0.078	0.886	0.0	2.450
801120356	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	668.	165.1	0.083	0.967	0.0	2.457
801120371	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	668.	165.1	0.081	0.982	0.0	2.467
801120386	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	669.	165.2	0.080	0.977	0.0	2.466
801120401	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	669.	165.3	0.078	0.985	0.0	2.507
801120416	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	671.	165.7	0.082	0.768	0.0	2.510
801120431	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	671.	164.6	0.081	0.782	0.0	2.485
801120446	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	672.	165.1	0.079	0.786	0.0	2.475
801120461	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	671.	165.0	0.078	0.792	0.0	2.505
801120476	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	672.	165.5	0.083	0.835	0.0	2.419
801121506	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	650.	163.1	0.083	0.816	0.0	2.401
801121521	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	656.	163.4	0.081	0.820	0.0	2.390

Table XVI (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801121536	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	659.	163.5	0.080	0.813	0.0	2.382
801121551	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	661.	163.5	0.079	0.803	0.0	2.339
801121566	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	665.	164.2	0.083	0.890	0.0	2.436
801121581	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	665.	164.2	0.080	0.884	0.0	2.439
801121596	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	663.	164.0	0.079	0.877	0.0	2.471
801121611	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	661.	164.0	0.078	0.886	0.0	4.236
801121626	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	656.	164.2	0.083	0.965	0.0	2.355
801121641	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	656.	164.5	0.081	0.977	0.0	2.369
801121656	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	655.	164.6	0.079	0.976	0.0	2.365
801121671	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	655.	164.8	0.078	0.980	0.0	2.355
801121686	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	656.	164.9	0.083	0.792	0.0	2.371
801121701	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	655.	165.0	0.081	0.790	0.0	2.356
801121716	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	655.	164.9	0.080	0.762	0.0	2.324
801121731	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	654.	165.2	0.078	0.783	0.0	2.342
801121746	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	655.	165.1	0.083	0.835	0.0	2.304
801121761	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	654.	165.1	0.081	0.830	0.0	2.315
801121776	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	655.	165.5	0.080	0.824	0.0	2.300
801121791	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	654.	165.4	0.078	0.823	0.0	2.303
801121806	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	655.	163.4	0.083	0.965	0.0	2.236
801121821	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	654.	163.5	0.081	0.897	0.0	2.270
801121836	LINER I-E, NOZ AB-G	AP	12.62	0.57	18166.	--	MAX CONTINUOUS	0.0	654.	163.5	0.080	0.890	0.0	2.257
801121851	LINER I-E, NOZ AB-G	AP	12.54	0.76	18111.	--	MAX CONTINUOUS	0.0	654.	163.5	0.078	0.867	0.0	2.263
801121866	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	655.	163.1	0.083	0.971	0.0	2.237
801121881	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	655.	163.2	0.081	0.955	0.0	2.237
801121896	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	655.	163.3	0.080	0.964	0.0	2.236
801121911	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	655.	163.5	0.078	0.956	0.0	2.219
801121926	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	657.	165.2	0.083	0.785	0.0	2.291

Table XVI (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801121941	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	658.	164.9	0.081	0.787	0.0	2.125
801121956	LINER I-E, NOZ AB-G	AP	12.62	0.57	18166.	--	MAX CONTINUOUS	0.0	657.	164.9	0.080	0.792	0.0	2.125
801121971	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	658.	165.2	0.078	0.784	0.0	2.070
801121986	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	658.	165.2	0.083	0.828	0.0	2.101
801121001	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	657.	165.3	0.081	0.836	0.0	2.107
801121016	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	657.	165.4	0.080	0.833	0.0	2.108
801121031	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	657.	165.7	0.078	0.827	0.0	2.120
801121046	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	656.	165.9	0.083	0.895	0.0	2.237
801121061	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	656.	166.1	0.081	0.894	0.0	2.239
801121076	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	656.	166.1	0.080	0.895	0.0	2.224
801121091	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	657.	166.3	0.078	0.889	0.0	2.162
801121106	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	657.	164.6	0.083	0.989	0.0	2.161
801121121	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	657.	164.5	0.081	0.990	0.0	2.173
801121136	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	657.	164.5	0.080	0.997	0.0	2.145
801121151	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	657.	164.5	0.079	0.989	0.0	2.173

Table XVI-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)
801113133	1.41	0.49	0.31	83.	13.	12.	36.	1568.	153.	0.00282	9.97	1498.	31. 45470.	54.	71.	57.
801113148	1.55	0.49	0.32	87.	12.	12.	38.	1514.	153.	0.00324	9.65	1495.	34. 51260.	22.	64.	61.
801113163	1.38	0.43	0.28	86.	12.	12.	39.	1423.	153.	0.00278	10.08	1696.	36. 44820.	17.	78.	64.
801120161	1.55	0.51	0.33	89.	13.	12.	35.	1326.	154.	0.00144	9.71	1498.	34. 52580.	30.	67.	59.
801120176	1.52	0.50	0.32	87.	13.	12.	37.	1373.	154.	0.00148	10.08	1453.	32. 47960.	9.	77.	58.
801120191	1.51	0.49	0.32	87.	13.	12.	37.	1372.	155.	0.00146	10.62	1449.	32. 48900.	9.	82.	60.
801120206	1.53	0.50	0.32	88.	13.	12.	37.	1369.	155.	0.00142	9.89	1452.	32. 49430.	9.	66.	64.
801120221	1.54	0.51	0.33	88.	13.	12.	36.	1380.	155.	0.00140	9.66	1449.	32. 53080.	7.	82.	55.
801120236	1.50	0.51	0.33	85.	13.	12.	36.	1384.	154.	0.00138	9.13	1412.	32. 48930.	8.	60.	59.
801120251	1.48	0.52	0.34	84.	13.	12.	35.	1381.	154.	0.00133	9.29	1400.	33. 51710.	5.	88.	61.
801120266	1.48	0.52	0.33	85.	13.	12.	35.	1382.	154.	0.00135	9.17	1398.	32. 52210.	5.	91.	63.
801120281	1.44	0.51	0.33	84.	13.	12.	35.	1365.	158.	0.00131	9.46	1399.	32. 52560.	5.	94.	64.
801120296	1.33	0.48	0.31	77.	12.	13.	37.	1329.	156.	0.00135	9.74	1338.	33. 50860.	5.	93.	65.
801120311	1.31	0.49	0.32	76.	13.	14.	37.	1311.	157.	0.00129	10.04	1341.	33. 49750.	4.	93.	67.
801120326	1.34	0.49	0.32	77.	12.	13.	37.	1327.	155.	0.00133	9.69	1353.	33. 50510.	5.	95.	67.
801120341	1.35	0.49	0.32	77.	12.	13.	37.	1329.	155.	0.00133	9.54	1356.	33. 50870.	5.	96.	67.
801120356	1.24	0.49	0.32	71.	12.	15.	37.	1327.	156.	0.00135	9.57	1361.	32. 51100.	4.	111.	70.
801120371	1.22	0.49	0.32	70.	12.	15.	37.	1318.	155.	0.00135	9.87	1375.	32. 50460.	4.	115.	82.
801120386	1.23	0.49	0.32	70.	12.	15.	37.	1302.	155.	0.00135	9.76	1384.	32. 49950.	5.	119.	86.
801120401	1.22	0.48	0.31	70.	12.	15.	38.	1299.	155.	0.00135	9.91	1390.	32. 49740.	5.	125.	90.
801120416	1.51	0.47	0.31	87.	12.	12.	38.	1511.	156.	0.00202	10.65	1479.	28. 41590.	3.	62.	54.
801120431	1.53	0.48	0.31	87.	12.	12.	38.	1511.	155.	0.00150	9.99	1466.	28. 41490.	5.	66.	57.
801120446	1.52	0.48	0.31	87.	12.	12.	38.	1508.	155.	0.00148	10.66	1464.	28. 41470.	5.	71.	61.
801120461	1.51	0.48	0.31	86.	12.	12.	38.	1510.	155.	0.00146	10.20	1462.	27. 41330.	5.	73.	63.
801120476	1.44	0.50	0.32	82.	13.	13.	37.	1474.	156.	0.00142	9.80	1442.	29. 48690.	2.	79.	51.

Table XVI-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)
801121506	1.47	0.50	0.32	84.	13.	12.	36.	1520.	154.	0.00158	9.32	1519.	28. 43870.	36.	69.	55.
801121521	1.47	0.50	0.32	84.	13.	12.	36.	1535.	154.	0.00160	9.45	1514.	28. 44010.	15.	74.	61.
801121536	1.48	0.50	0.32	84.	13.	12.	36.	1540.	154.	0.00163	9.31	1502.	28. 44370.	11.	80.	65.
801121551	1.50	0.52	0.33	85.	13.	12.	35.	1549.	154.	0.00160	9.06	1475.	28. 44780.	8.	85.	69.
801121566	1.35	0.49	0.32	77.	13.	13.	37.	1543.	155.	0.00158	9.68	1460.	28. 43260.	20.	79.	65.
801121581	1.35	0.49	0.32	77.	13.	13.	37.	1538.	155.	0.00158	9.55	1443.	28. 42950.	8.	79.	65.
801121596	1.37	0.42	0.28	78.	11.	13.	44.	1530.	155.	0.00160	9.38	1421.	28. 41990.	5.	77.	66.
801121611	1.35	0.28	0.21	77.	7.	13.	64.	1529.	154.	0.00160	9.56	1410.	27. 42350.	4.	78.	66.
801121626	1.22	0.51	0.32	70.	13.	15.	36.	1535.	154.	0.00158	9.91	1406.	29. 44130.	5.	112.	92.
801121641	1.23	0.51	0.32	71.	13.	15.	36.	1529.	155.	0.00156	9.74	1416.	29. 43850.	2.	113.	93.
801121656	1.23	0.50	0.32	71.	13.	15.	36.	1526.	155.	0.00156	9.71	1419.	28. 43760.	1.	117.	96.
801121671	1.22	0.51	0.32	71.	13.	15.	35.	1523.	155.	0.00154	9.77	1421.	28. 43550.	1.	122.	100.
801121686	1.51	0.51	0.32	87.	13.	12.	36.	1478.	155.	0.00154	10.00	1539.	29. 48640.	3.	78.	58.
801121701	1.52	0.51	0.32	88.	13.	12.	35.	1484.	155.	0.00154	9.93	1532.	29. 48280.	1.	82.	61.
801121716	1.54	0.52	0.33	89.	13.	12.	35.	1484.	155.	0.00856	9.75	1528.	28. 48070.	0.	88.	75.
801121731	1.53	0.51	0.33	89.	13.	12.	35.	1473.	155.	0.00313	9.76	1524.	28. 48670.	1.	93.	71.
801121746	1.44	0.52	0.32	83.	13.	12.	34.	1540.	155.	0.00198	9.68	1566.	28. 44460.	2.	78.	64.
801121761	1.45	0.52	0.32	84.	13.	12.	35.	1545.	156.	0.00175	9.55	1547.	28. 44310.	0.	82.	67.
801121776	1.46	0.52	0.32	84.	13.	12.	34.	1545.	156.	0.00163	9.40	1515.	27. 44490.	1.	82.	66.
801121791	1.46	0.52	0.32	85.	13.	12.	34.	1551.	156.	0.00160	9.37	1499.	27. 44430.	1.	83.	67.
801121806	1.33	0.54	0.32	76.	14.	14.	34.	1525.	153.	0.00135	9.95	1466.	28. 42810.	1.	88.	73.
801121821	1.34	0.53	0.31	77.	14.	13.	34.	1523.	154.	0.00140	9.77	1460.	27. 43280.	1.	92.	76.
801121836	1.35	0.53	0.32	77.	14.	13.	34.	1521.	154.	0.00131	9.61	1448.	27. 43370.	1.	94.	77.
801121851	1.35	0.53	0.31	78.	14.	13.	34.	1526.	154.	0.00121	9.55	1441.	27. 43030.	1.	96.	80.
801121866	1.23	0.54	0.32	70.	14.	15.	34.	1525.	153.	0.00119	9.65	1437.	29. 44240.	2.	115.	92.

Table XVI-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801121881	1.26	0.54	0.32	72.	14.	14.	34.	1530.	154.	0.00098	9.32	1397.	29.	44210.	0.	112.	90.
801121896	1.25	0.54	0.32	71.	14.	14.	34.	1533.	154.	0.00098	9.49	1387.	28.	44290.	0.	113.	91.
801121911	1.25	0.54	0.32	72.	14.	14.	33.	1530.	154.	0.00131	9.32	1384.	28.	44190.	0.	113.	92.
801121926	1.53	0.57	0.32	88.	15.	12.	31.	1541.	155.	0.00094	9.90	1456.	29.	45450.	0.	86.	69.
801121941	1.53	0.57	0.32	88.	15.	12.	32.	1536.	155.	0.00123	9.94	1456.	28.	45610.	0.	94.	73.
801121956	1.52	0.57	0.32	87.	15.	12.	32.	1523.	155.	0.00094	10.06	1461.	28.	46180.	0.	99.	76.
801121971	1.53	0.58	0.32	89.	15.	12.	31.	1523.	155.	0.00092	9.85	1460.	28.	46000.	0.	104.	80.
801121986	1.45	0.57	0.33	84.	15.	12.	31.	1545.	156.	0.00092	9.54	1421.	28.	47790.	1.	94.	70.
801121001	1.44	0.57	0.33	83.	15.	12.	31.	1536.	156.	0.00092	9.72	1419.	28.	47750.	0.	95.	70.
801121016	1.44	0.57	0.33	83.	15.	12.	31.	1521.	156.	0.00092	9.62	1413.	27.	47860.	0.	97.	72.
801121031	1.45	0.57	0.33	84.	15.	12.	32.	1502.	156.	0.00092	9.49	1406.	27.	47630.	0.	97.	72.
801121046	1.34	0.54	0.33	78.	14.	13.	33.	1537.	156.	0.00085	9.64	1360.	28.	47290.	0.	96.	72.
801121061	1.34	0.54	0.33	78.	14.	13.	33.	1549.	156.	0.00087	9.60	1372.	28.	46890.	0.	96.	74.
801121076	1.34	0.54	0.33	78.	14.	13.	33.	1548.	156.	0.00085	9.62	1372.	28.	47110.	0.	102.	77.
801121091	1.35	0.55	0.33	79.	14.	13.	32.	1550.	157.	0.00083	9.49	1392.	28.	47110.	0.	103.	77.
801121106	1.21	0.56	0.32	70.	14.	15.	32.	1546.	155.	0.00087	9.94	1521.	29.	45750.	0.	119.	92.
801121121	1.22	0.55	0.32	70.	14.	15.	33.	1534.	155.	0.00085	9.96	1513.	29.	45050.	0.	120.	95.
801121136	1.20	0.56	0.32	69.	14.	15.	32.	1531.	154.	0.00083	10.11	1502.	28.	44820.	0.	125.	99.
801121151	1.21	0.55	0.31	70.	14.	15.	33.	1529.	154.	0.00081	9.96	1438.	28.	44610.	0.	127.	101.

Table XVI-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801113133	0.0	99.82	0.	0.45	1.035	1.40	0.55
801113148	0.0	99.90	0.	0.90	1.123	1.50	0.50
801113163	0.0	99.89	3.	0.91	1.112	1.50	0.50
801120161	0.0	99.88	8.	1.49	1.119	1.50	0.50
801120176	109.66	99.92	0.	1.30	1.043	1.50	0.50
801120191	77.03	99.92	0.	1.30	1.069	1.50	0.50
801120206	61.30	99.92	0.	1.33	1.071	1.50	0.50
801120221	0.0	99.93	0.	1.32	1.136	1.50	0.50
801120236	0.0	99.92	3.	1.31	1.029	1.40	0.50
801120251	110.67	99.93	0.	1.33	1.079	1.40	0.50
801120266	76.92	99.93	0.	1.33	1.096	1.40	0.50
801120281	60.70	99.93	0.	1.33	1.127	1.40	0.50
801120296	0.0	99.93	4.	1.49	1.136	1.30	0.50
801120311	129.43	99.93	0.	1.52	1.105	1.30	0.50
801120326	86.08	99.93	0.	1.49	1.111	1.30	0.50
801120341	65.14	99.93	0.	1.51	1.115	1.30	0.50
801120356	0.0	99.93	0.	1.40	1.121	1.20	0.50
801120371	157.27	99.92	0.	1.40	1.115	1.20	0.50
801120386	110.77	99.92	0.	1.46	1.100	1.20	0.50
801120401	89.06	99.92	0.	1.47	1.110	1.20	0.50
801120416	0.0	99.93	0.	0.90	0.942	1.50	0.55
801120431	111.19	99.93	0.	0.90	0.923	1.50	0.55
801120446	80.36	99.93	0.	0.89	0.922	1.50	0.55
801120461	63.16	99.93	0.	0.90	0.925	1.50	0.55
801120476	0.0	99.94	0.	1.01	1.068	1.40	0.55
801121506	0.0	99.86	0.	0.73	0.963	1.40	0.55

Table XVI-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801121521	115.32	99.91	0.	0.68	0.955	1.40	0.55
801121536	82.88	99.92	0.	0.67	0.961	1.40	0.55
801121551	65.06	99.92	0.	0.67	0.951	1.40	0.55
801121566	0.0	99.89	3.	0.67	0.958	1.30	0.55
801121581	126.74	99.92	0.	0.69	0.949	1.30	0.55
801121596	95.23	99.93	0.	0.72	1.032	1.30	0.55
801121611	95.48	99.93	0.	0.72	1.386	1.30	0.55
801121626	0.0	99.92	3.	0.71	0.971	1.20	0.55
801121641	177.57	99.92	0.	0.70	0.959	1.20	0.55
801121656	124.78	99.92	0.	0.70	0.963	1.20	0.55
801121671	97.26	99.92	0.	0.72	0.950	1.20	0.55
801121686	0.0	99.94	3.	0.79	1.061	1.50	0.60
801121701	115.36	99.94	0.	0.81	1.043	1.50	0.60
801121716	94.00	99.94	0.	0.79	1.027	1.50	0.60
801121731	67.73	99.94	0.	0.82	1.046	1.50	0.60
801121746	0.0	99.94	3.	0.52	0.970	1.40	0.60
801121761	126.56	99.94	0.	0.57	0.963	1.40	0.60
801121776	84.66	99.94	0.	0.57	0.964	1.40	0.60
801121791	64.63	99.94	0.	0.57	0.961	1.40	0.60
801121806	0.0	99.93	3.	0.53	0.948	1.30	0.60
801121821	148.53	99.93	0.	0.53	0.965	1.30	0.60
801121836	101.04	99.93	0.	0.54	0.961	1.30	0.60
801121851	78.58	99.93	0.	0.52	0.958	1.30	0.60
801121866	0.0	99.92	3.	0.58	0.973	1.20	0.60
801121881	171.02	99.93	0.	0.57	0.961	1.20	0.60
801121896	116.75	99.93	0.	0.57	0.968	1.20	0.60

Table XVI-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801121911	88.45	99.93	0.	0.59	0.959	1.20	0.60
801121926	0.0	99.94	3.	0.57	0.989	1.50	0.65
801121941	140.07	99.94	0.	0.58	0.995	1.50	0.65
801121956	98.47	99.94	0.	0.59	1.008	1.50	0.65
801121971	76.74	99.93	0.	0.61	0.992	1.50	0.65
801121986	0.0	99.94	3.	0.56	1.025	1.40	0.65
801121001	131.86	99.94	0.	0.57	1.023	1.40	0.65
801121016	90.28	99.94	0.	0.57	1.028	1.40	0.65
801121031	69.09	99.94	0.	0.58	1.023	1.40	0.65
801121046	0.0	99.94	3.	0.61	1.014	1.30	0.65
801121061	138.69	99.94	0.	0.60	1.002	1.30	0.65
801121076	96.00	99.94	0.	0.60	1.005	1.30	0.65
801121091	71.70	99.94	0.	0.60	0.984	1.30	0.65
801121106	0.0	99.93	3.	0.61	1.017	1.20	0.65
801121121	183.72	99.93	0.	0.61	1.001	1.20	0.65
801121136	128.51	99.93	0.	0.60	0.991	1.20	0.65
801121151	99.42	99.92	0.	0.60	0.989	1.20	0.60
801121166	0.0	99.95	3.	1.06	1.156	1.50	0.50
801121181	0.0	99.95	3.	0.65	1.115	1.50	0.60
801121230	0.0	99.94	3.	0.59	1.052	1.50	0.50
801121245	135.31	99.94	0.	0.59	1.041	1.50	0.50
801121260	94.74	99.94	0.	0.59	1.039	1.50	0.50
801121275	74.03	99.94	0.	0.58	1.035	1.50	0.50
801121290	0.0	99.94	3.	1.04	1.076	1.35	0.50
801121305	119.49	99.95	0.	1.04	1.076	1.35	0.50
801121320	82.04	99.95	0.	1.03	1.078	1.35	0.50

Table XVI-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801121335	64.67	99.94	0.	1.03	1.078	1.35	0.50
801121350	0.0	99.93	3.	1.10	1.044	1.20	0.50
801121365	145.25	99.94	0.	1.11	1.054	1.20	0.50
801121380	97.72	99.94	0.	1.10	1.038	1.20	0.50
801121395	73.15	99.94	3.	1.10	1.026	1.20	0.50
801121410	0.0	99.93	3.	0.69	1.023	1.50	0.60
801121424	135.06	99.94	0.	0.68	1.018	1.50	0.60
801121439	73.55	99.94	0.	0.67	1.004	1.50	0.60
801121454	0.0	99.94	3.	0.65	1.048	1.35	0.60
801121469	119.07	99.95	0.	0.62	1.047	1.35	0.60
801121484	59.23	99.95	0.	0.63	1.045	1.35	0.60
801121499	0.0	99.94	3.	0.62	1.036	1.20	0.60
801121514	143.41	99.94	0.	0.61	1.022	1.20	0.60
801121529	75.44	99.94	0.	0.61	1.029	1.20	0.60
801121544	0.0	99.93	3.	0.55	1.013	1.50	0.50
801121559	153.02	99.93	0.	0.58	1.009	1.50	0.50
801121574	85.74	99.93	0.	0.63	1.021	1.50	0.50
801121589	0.0	99.94	3.	0.59	1.049	1.35	0.50
801121504	154.81	99.94	0.	0.61	1.039	1.35	0.50
801121619	79.34	99.94	0.	0.65	1.043	1.35	0.50
801121634	0.0	99.93	3.	0.60	1.041	1.50	0.60
801121549	183.52	99.93	0.	0.53	1.029	1.50	0.60
801121564	108.33	99.92	0.	0.56	1.023	1.50	0.60
801121579	0.0	99.94	3.	0.52	1.018	1.35	0.60
801121594	145.21	99.94	0.	0.52	1.013	1.35	0.60
801121709	77.84	99.94	0.	0.51	1.011	1.35	0.60

Table XVII.

RQL combustor parametric data: pressure drop--ERBS fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801121166	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	658.	165.1	0.083	0.789	0.0	2.416
801121181	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	658.	165.2	0.083	0.780	0.0	2.345
801121230	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	659.	165.1	0.083	0.775	0.0	2.314
801121245	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	660.	165.8	0.081	0.765	0.0	2.257
801121260	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	661.	166.0	0.080	0.762	0.0	2.262
801121275	LINER I-E, NOZ AB-G	AP	12.54	0.76	18111.	--	MAX CONTINUOUS	0.0	661.	166.2	0.078	0.764	0.0	2.247
801121290	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	659.	167.2	0.083	0.808	0.0	2.413
801121305	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	659.	167.7	0.081	0.851	0.0	2.377
801121320	LINER I-E, NOZ AB-G	AP	12.62	0.57	18165.	--	MAX CONTINUOUS	0.0	659.	167.7	0.080	0.851	0.0	2.379
801121335	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	658.	167.9	0.078	0.852	0.0	2.382
801121350	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	659.	166.3	0.083	0.968	0.0	2.508
801121365	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	657.	166.7	0.031	0.961	0.0	2.504
801121380	LINER I-E, NOZ AB-G	AP	12.62	0.57	18166.	--	MAX CONTINUOUS	0.0	658.	166.7	0.080	0.966	0.0	2.455
801121395	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	658.	167.1	0.079	0.953	0.0	2.423
801121410	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	660.	165.7	0.083	0.775	0.0	2.061
801121424	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	660.	166.2	0.081	0.773	0.0	2.041
801121439	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	660.	166.0	0.079	0.775	0.0	2.034
801121454	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	660.	163.8	0.083	0.842	0.0	2.066
801121469	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	660.	163.2	0.081	0.855	0.0	2.021
801121484	LINER I-E, NOZ AB-G	AP	12.55	0.78	18142.	--	MAX CONTINUOUS	0.0	660.	163.1	0.079	0.859	0.0	2.046
801121499	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	660.	164.2	0.083	0.963	0.0	2.224
801121514	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	662.	164.5	0.081	0.963	0.0	2.227
801121529	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	662.	165.2	0.078	0.961	0.0	2.222
801121544	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	663.	165.9	0.083	0.770	0.0	2.035
801121559	LINER I-E, NOZ AB-G	AP	12.71	0.38	18220.	--	MAX CONTINUOUS	0.0	663.	165.4	0.081	0.762	0.0	2.033
801121574	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	662.	165.1	0.079	0.765	0.0	2.024
801121589	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	662.	164.2	0.083	0.862	0.0	2.032

Table XVII (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801121604	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	662.	164.3	0.081	0.857	0.0	2.085
801121619	LINER I-E, NOZ AB-G	AP	12.54	0.75	18111.	--	MAX CONTINUOUS	0.0	661.	164.6	0.078	0.850	0.0	2.078
801121634	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	662.	163.9	0.083	0.751	0.0	1.767
801121649	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	662.	164.0	0.081	0.747	0.0	1.704
801121664	LINER I-E, NOZ AB-G	AP	12.54	0.75	18112.	--	MAX CONTINUOUS	0.0	662.	164.6	0.079	0.740	0.0	1.737
801121579	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	662.	165.3	0.083	0.852	0.0	1.918
801121694	LINER I-E, NOZ AB-G	AP	12.71	0.38	18219.	--	MAX CONTINUOUS	0.0	662.	165.8	0.081	0.853	0.0	1.898
801121709	LINER I-E, NOZ AB-G	AP	12.54	0.76	18111.	--	MAX CONTINUOUS	0.0	661.	166.3	0.078	0.844	0.0	1.901

Table XVII-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801121166	1.52	0.50	0.32	88.	13.	12.	36.	1444.	155.	0.00083	9.99	1530.	31.	52950.	0.	83.	55.
801121181	1.53	0.51	0.32	89.	13.	12.	35.	1515.	155.	0.00083	9.75	1578.	28.	50480.	0.	73.	51.
801121230	1.54	0.52	0.32	89.	13.	12.	35.	1560.	157.	0.00081	8.01	1497.	29.	47240.	0.	85.	64.
801121245	1.57	0.53	0.32	91.	14.	11.	34.	1563.	158.	0.00083	7.78	1483.	28.	48010.	0.	97.	71.
801121260	1.58	0.53	0.32	91.	14.	11.	34.	1559.	158.	0.00083	7.71	1465.	28.	47880.	0.	100.	74.
801121275	1.57	0.53	0.32	91.	14.	11.	34.	1557.	158.	0.00083	7.73	1455.	28.	47790.	0.	104.	77.
801121290	1.38	0.50	0.33	81.	13.	13.	36.	1490.	159.	0.00081	8.02	1372.	30.	49880.	0.	95.	67.
801121305	1.41	0.51	0.33	83.	13.	13.	35.	1499.	160.	0.00081	7.68	1383.	30.	50780.	0.	92.	65.
801121320	1.41	0.50	0.33	83.	13.	12.	35.	1499.	160.	0.00081	7.68	1383.	29.	50750.	0.	94.	66.
801121335	1.41	0.50	0.33	83.	13.	12.	35.	1497.	160.	0.00079	7.68	1385.	29.	50790.	0.	98.	69.
801121350	1.24	0.48	0.32	72.	12.	14.	37.	1475.	158.	0.00081	7.98	1464.	31.	47320.	0.	106.	79.
801121365	1.25	0.48	0.32	73.	12.	14.	37.	1479.	159.	0.00081	7.64	1455.	30.	48130.	0.	104.	76.
801121380	1.25	0.49	0.32	72.	13.	14.	36.	1477.	159.	0.00081	7.93	1443.	30.	47960.	0.	104.	77.
801121395	1.26	0.50	0.33	74.	13.	14.	36.	1476.	159.	0.00083	7.69	1430.	30.	47950.	0.	104.	77.
801121410	1.55	0.58	0.31	89.	15.	12.	31.	1524.	158.	0.00081	7.95	1526.	29.	45080.	2.	85.	66.
801121424	1.56	0.59	0.31	90.	15.	11.	30.	1517.	158.	0.00081	7.89	1508.	28.	45460.	0.	88.	69.
801121439	1.55	0.59	0.31	90.	15.	11.	30.	1518.	158.	0.00083	7.93	1488.	29.	44960.	0.	94.	74.
801121454	1.43	0.58	0.32	81.	15.	13.	31.	1531.	156.	0.00083	7.65	1423.	28.	48230.	0.	86.	64.
801121469	1.40	0.59	0.33	80.	15.	13.	31.	1536.	155.	0.00087	7.93	1410.	28.	48650.	0.	87.	63.
801121484	1.40	0.59	0.32	80.	15.	13.	31.	1531.	155.	0.00087	7.99	1397.	27.	48290.	0.	87.	64.
801121499	1.25	0.54	0.32	71.	14.	14.	34.	1552.	156.	0.00085	8.01	1313.	28.	47840.	0.	102.	76.
801121514	1.25	0.54	0.32	71.	14.	14.	34.	1549.	156.	0.00115	8.01	1310.	28.	47340.	0.	101.	75.
801121529	1.25	0.54	0.32	72.	14.	14.	33.	1546.	157.	0.00085	7.95	1312.	27.	47670.	0.	106.	79.
801121544	1.56	0.59	0.33	90.	15.	11.	30.	1599.	160.	0.00081	6.30	1338.	29.	47060.	1.	102.	77.
801121559	1.59	0.59	0.33	91.	15.	11.	31.	1592.	159.	0.00083	6.19	1314.	29.	47530.	0.	110.	82.
801121574	1.57	0.59	0.33	90.	15.	11.	30.	1586.	159.	0.00083	6.24	1393.	28.	48070.	[illegible]	122.	91.

Table XVII-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801121589	1.39	0.58	0.33	79.	15.	13.	31.	1573.	158.	0.00781	6.43	1525.	29.	48590.	0.	100.	83.
801121504	1.40	0.58	0.33	80.	15.	13.	32.	1564.	158.	0.00783	6.35	1510.	29.	48370.	0.	99.	83.
801121519	1.41	0.58	0.33	81.	15.	13.	31.	1552.	158.	0.00747	6.23	1500.	28.	48660.	0.	102.	84.
801121534	1.60	0.63	0.32	91.	17.	11.	27.	1553.	158.	0.00395	6.06	1505.	30.	47680.	0.	114.	90.
801121549	1.61	0.63	0.32	92.	17.	11.	27.	1558.	158.	0.00261	5.99	1501.	30.	47300.	0.	125.	97.
801121564	1.62	0.69	0.33	93.	18.	11.	26.	1554.	159.	0.00461	5.86	1521.	30.	47700.	0.	142.	113.
801121679	1.41	0.63	0.33	81.	16.	13.	29.	1587.	159.	0.00152	6.23	1487.	28.	47130.	0.	101.	77.
801121694	1.40	0.63	0.33	81.	16.	13.	28.	1582.	160.	0.00146	6.24	1467.	28.	47160.	0.	102.	78.
801121709	1.42	0.63	0.33	82.	16.	13.	28.	1564.	160.	0.00146	6.09	1453.	28.	47210.	0.	108.	82.

Table XVII-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801125116	0.0	99.88	0.	0.59	1.026	1.40	0.55
801125131	0.0	99.92	0.	1.61	1.270	1.50	0.50
801125145	0.0	99.93	0.	1.64	1.224	1.50	0.50
801125160	0.0	99.92	3.	0.61	0.927	1.50	0.60
801125175	0.0	99.95	2.	0.66	1.026	1.50	0.50
801125190	144.18	99.95	0.	0.69	1.010	1.50	0.50
801125205	80.37	99.95	0.	0.67	1.018	1.50	0.50
801125220	0.0	99.94	2.	0.74	1.008	1.35	0.50
801125235	150.74	99.94	0.	0.79	1.027	1.35	0.50
801125250	77.53	99.95	0.	0.82	1.019	1.35	0.50
801125265	0.0	99.94	2.	0.76	1.022	1.30	0.50
801125280	169.96	99.94	0.	0.76	1.006	1.30	0.50
801125295	86.54	99.94	0.	0.77	0.993	1.30	0.50
801125310	0.0	99.95	2.	0.79	1.689	1.50	0.60
801125325	161.37	99.95	0.	0.79	1.659	1.50	0.60
801125340	88.60	99.95	0.	0.77	1.070	1.50	0.60
801125355	0.0	99.95	3.	0.76	1.040	1.35	0.60
801125370	157.10	99.95	0.	0.76	1.030	1.35	0.60

Table XVII-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801125385	82.78	99.95	0.	0.76	1.037	1.35	0.60
801125400	0.0	99.94	3.	0.73	1.020	1.30	0.60
801125415	188.45	99.94	0.	0.71	0.998	1.30	0.60
801125430	92.56	99.94	0.	0.69	1.006	1.30	0.60
801125444	0.0	99.93	3.	0.56	1.013	1.50	0.50
801125460	183.38	99.94	0.	0.55	0.996	1.50	0.50
801125475	103.01	99.94	0.	0.58	0.998	1.50	0.50
801125490	0.0	99.94	3.	0.55	1.003	1.35	0.50
801125505	228.64	99.94	0.	0.56	0.991	1.35	0.50
801125520	119.65	99.94	0.	0.56	0.999	1.35	0.50
801125535	0.0	99.93	3.	0.55	0.974	1.50	0.60
801125550	0.0	99.77	0.	0.61	1.059	1.50	0.60
801125565	210.96	99.85	0.	0.61	1.044	1.50	0.60
801125580	104.26	99.87	0.	0.60	1.027	1.50	0.60
801125595	0.0	99.90	3.	0.63	1.034	1.35	0.60
801125611	187.05	99.93	0.	0.60	1.006	1.35	0.60
801125626	98.66	99.93	0.	0.57	1.007	1.35	0.60

Table XVIII.

RQL combustor parametric data: residence time--ERBS fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801125116	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	657.	163.8	0.082	0.796	0.0	2.371
801125131	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	660.	163.5	0.082	0.795	0.0	2.473
801125145	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	661.	163.8	0.082	0.798	0.0	2.482
801125160	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONTINUOUS	0.0	666.	163.8	0.083	0.772	0.0	2.378
801125175	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+15%WA	0.0	660.	166.3	0.097	0.916	0.0	2.753
801125190	LINER I-E, NOZ AB-G	AP	12.73	0.33	18234.	--	MAX CONT+15%WA	0.0	660.	166.4	0.094	0.910	0.0	2.727
801125205	LINER I-E, NOZ AB-G	AP	12.58	0.65	18141.	--	MAX CONT+15%WA	0.0	660.	166.9	0.091	0.899	0.0	2.715
801125220	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+15%WA	0.0	661.	166.8	0.097	1.002	0.0	2.765
801125235	LINER I-E, NOZ AB-G	AP	12.73	0.33	18235.	--	MAX CONT+15%WA	0.0	661.	166.6	0.095	1.000	0.0	2.780
801125250	LINER I-E, NOZ AB-G	AP	12.58	0.65	18141.	--	MAX CONT+15%WA	0.0	660.	166.7	0.092	1.000	0.0	2.753
801125265	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+15%WA	0.0	665.	164.8	0.097	1.049	0.0	2.654
801125280	LINER I-E, NOZ AB-G	AP	12.73	0.33	18234.	--	MAX CONT+15%WA	0.0	664.	164.9	0.094	1.056	0.0	2.648
801125295	LINER I-E, NOZ AB-G	AP	12.59	0.65	18142.	--	MAX CONT+15%WA	0.0	664.	164.9	0.092	1.054	0.0	2.621
801125310	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+15%WA	0.0	663.	164.7	0.096	0.926	0.0	2.556
801125325	LINER I-E, NOZ AB-G	AP	12.73	0.33	18234.	--	MAX CONT+15%WA	0.0	664.	164.3	0.095	0.922	0.0	2.552
801125340	LINER I-E, NOZ AB-G	AP	12.58	0.65	18141.	--	MAX CONT+15%WA	0.0	664.	163.8	0.092	0.925	0.0	2.509
801125355	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+15%WA	0.0	664.	163.8	0.096	1.010	0.0	2.440
801125370	LINER I-E, NOZ AB-G	AP	12.73	0.33	18234.	--	MAX CONT+15%WA	0.0	663.	163.9	0.094	1.008	0.0	2.428
801125385	LINER I-E, NOZ AB-G	AP	12.58	0.65	18141.	--	MAX CONT+15%WA	0.0	661.	163.8	0.092	0.988	0.0	2.415
801125400	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+15%WA	0.0	661.	163.0	0.097	1.036	0.0	2.424
801125415	LINER I-E, NOZ AB-G	AP	12.73	0.33	18234.	--	MAX CONT+15%WA	0.0	661.	163.2	0.095	1.044	0.0	2.429
801125430	LINER I-E, NOZ AB-G	AP	12.59	0.65	18142.	--	MAX CONT+15%WA	0.0	660.	163.4	0.092	1.044	0.0	2.420
801125444	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+30%WA	0.0	663.	166.3	0.107	1.029	0.0	2.625

Table XVIII (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801125460	LINER I-E, NOZ AB-G	AP	12.75	0.30	18243.	--	MAX CONT+30%WA	0.0	662.	166.2	0.105	1.034	0.0	2.022
801125475	LINER I-E, NOZ AB-G	AP	12.61	0.59	18160.	--	MAX CONT+30%WA	0.0	662.	166.4	0.102	1.040	0.0	2.030
801125490	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+30%WA	0.0	662.	166.5	0.107	1.056	0.0	2.050
801125505	LINER I-E, NOZ AB-G	AP	12.75	0.30	18243.	--	MAX CONT+30%WA	0.0	661.	166.4	0.105	1.066	0.0	2.021
801125520	LINER I-E, NOZ AB-G	AP	12.61	0.59	18159.	--	MAX CONT+30%WA	0.0	659.	166.1	0.102	1.068	0.0	2.037
801125535	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+30%WA	0.0	660.	166.1	0.107	1.016	0.0	2.425
801125550	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+30%WA	0.0	659.	164.8	0.107	1.017	0.0	2.536
801125565	LINER I-E, NOZ AB-G	AP	12.75	0.30	18243.	--	MAX CONT+30%WA	0.0	660.	164.9	0.105	1.019	0.0	2.526
801125580	LINER I-E, NOZ AB-G	AP	12.61	0.59	18159.	--	MAX CONT+30%WA	0.0	660.	165.0	0.102	1.022	0.0	2.525
801125595	LINER I-E, NOZ AB-G	A	12.88	0.01	18327.	--	MAX CONT+30%WA	0.0	661.	165.3	0.107	1.060	0.0	2.554
801125611	LINER I-E, NOZ AB-G	AP	12.75	0.30	18243.	--	MAX CONT+30%WA	0.0	662.	165.5	0.105	1.050	0.0	2.528
801125626	LINER I-E, NOZ AB-G	AP	12.61	0.59	18160.	--	MAX CONT+30%WA	0.0	662.	165.6	0.103	1.064	0.0	2.533

Table XVIII-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801125116	1.49	0.50	0.32	86.	13.	12.	36.	1542.	155.	0.00085	8.99	1551.	25.	46270.	32.	78.	60.
801125131	1.49	0.48	0.32	86.	12.	12.	38.	1287.	153.	0.00092	10.20	1540.	31.	56840.	16.	95.	60.
801125145	1.49	0.48	0.31	86.	12.	12.	38.	1277.	154.	0.00096	10.26	1526.	30.	54560.	8.	92.	60.
801125160	1.55	0.50	0.32	88.	13.	12.	36.	1548.	154.	0.00108	9.65	1535.	26.	42070.	10.	69.	58.
801125175	1.52	0.51	0.33	76.	11.	14.	41.	1565.	157.	0.00106	9.57	1458.	28.	47500.	0.	84.	63.
801125190	1.53	0.51	0.33	77.	11.	13.	41.	1547.	157.	0.00112	9.43	1440.	28.	47160.	0.	86.	67.
801125205	1.54	0.51	0.33	78.	11.	13.	40.	1549.	158.	0.00108	9.19	1427.	27.	47560.	0.	98.	73.
801125220	1.39	0.50	0.33	69.	11.	15.	41.	1487.	158.	0.00102	9.24	1325.	29.	46940.	0.	93.	70.
801125235	1.40	0.50	0.33	70.	11.	15.	41.	1485.	157.	0.00102	9.21	1321.	29.	47990.	0.	94.	70.
801125250	1.39	0.51	0.33	70.	11.	15.	41.	1481.	157.	0.00102	9.19	1318.	28.	47730.	0.	95.	71.
801125265	1.33	0.49	0.32	65.	11.	16.	43.	1473.	155.	0.00104	9.53	1267.	29.	46490.	0.	99.	76.
801125280	1.32	0.49	0.32	65.	11.	16.	43.	1474.	155.	0.00104	9.68	1264.	29.	45820.	0.	99.	77.
801125295	1.32	0.49	0.32	65.	11.	16.	43.	1474.	155.	0.00104	9.60	1261.	29.	45550.	0.	99.	77.
801125310	1.50	0.54	0.32	74.	12.	14.	39.	1501.	155.	0.00102	9.96	1323.	28.	49100.	0.	98.	71.
801125325	1.52	0.55	0.32	74.	12.	14.	39.	1494.	154.	0.00102	9.90	1326.	28.	48190.	0.	99.	73.
801125340	1.51	0.56	0.32	74.	12.	14.	38.	1497.	154.	0.00102	10.01	1335.	27.	49050.	0.	109.	79.
801125355	1.38	0.57	0.32	68.	12.	15.	37.	1475.	154.	0.00102	9.58	1323.	27.	47980.	0.	97.	72.
801125370	1.38	0.57	0.33	68.	13.	15.	37.	1484.	154.	0.00100	9.52	1327.	28.	47770.	0.	97.	73.
801125385	1.41	0.59	0.33	69.	13.	15.	37.	1485.	155.	0.00100	9.15	1326.	27.	48610.	0.	103.	75.
801125400	1.35	0.58	0.32	66.	13.	16.	37.	1501.	154.	0.01523	9.39	1355.	28.	46570.	0.	100.	100.
801125415	1.34	0.53	0.32	65.	13.	16.	37.	1493.	154.	0.00717	9.48	1332.	28.	45580.	0.	97.	65.
801125430	1.34	0.53	0.32	66.	13.	16.	37.	1497.	154.	0.00334	9.47	1319.	27.	45980.	0.	102.	62.
801125444	1.50	0.59	0.32	67.	12.	15.	39.	1539.	156.	0.00150	9.48	1436.	32.	45600.	0.	92.	72.

Table XVIII-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801125460	1.49	0.59	0.32	67.	12.	15.	39.	1535.	156.	0.00146	10.00	1425.	32.	44950.	0.	93.	74.
801125475	1.49	0.59	0.31	67.	12.	15.	39.	1531.	156.	0.00309	10.10	1421.	32.	44900.	0.	99.	81.
801125490	1.46	0.58	0.32	66.	12.	16.	40.	1536.	157.	0.00123	9.56	1370.	32.	45060.	0.	90.	72.
801125505	1.45	0.59	0.32	65.	12.	16.	39.	1534.	157.	0.01455	9.69	1360.	32.	44940.	0.	91.	93.
801125520	1.44	0.58	0.31	65.	12.	16.	39.	1534.	156.	0.01208	9.73	1354.	32.	45010.	0.	97.	95.
801125535	1.52	0.64	0.32	68.	13.	15.	36.	1555.	156.	0.00545	9.68	1371.	35.	44070.	0.	95.	83.
801125550	1.52	0.61	0.32	68.	12.	15.	38.	1576.	155.	0.00809	9.75	1459.	32.	47730.	76.	96.	84.
801125565	1.51	0.61	0.32	68.	12.	15.	38.	1569.	155.	0.00689	9.80	1460.	32.	47200.	36.	102.	86.
801125580	1.51	0.61	0.32	68.	12.	15.	38.	1569.	155.	0.00305	9.85	1450.	32.	46410.	29.	104.	83.
801125595	1.46	0.60	0.32	65.	12.	16.	38.	1563.	156.	0.00165	9.65	1415.	31.	47060.	17.	103.	79.
801125611	1.47	0.61	0.32	66.	12.	16.	38.	1566.	156.	0.00085	9.47	1414.	31.	46390.	2.	101.	76.
801125526	1.46	0.61	0.32	65.	12.	16.	38.	1581.	156.	0.00087	9.73	1404.	31.	46440.	0.	105.	80.

Table XIX.

RQL combustor parametric data: inlet temperature, initial pressure drop, fuel temperature--RESID fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801209129	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	549.	156.8	0.082	0.657	0.0	2.119
801209144	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	584.	160.1	0.082	0.849	0.0	2.188
801209159	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	612.	160.8	0.082	0.843	0.0	2.203
801209174	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	639.	161.5	0.082	0.844	0.0	2.188
801209189	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	654.	163.2	0.082	0.844	0.0	2.220
801209204	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	654.	163.3	0.082	0.755	0.0	1.925
801209219	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	655.	163.6	0.082	0.844	0.0	2.153
801209234	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	656.	163.4	0.082	0.944	0.0	2.133
801209249	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	657.	163.9	0.082	0.738	0.0	1.681
801209264	LINER I-F, NOZ AB-H	BP	11.11	0.63	17837.	250.	MAX CONTINUOUS	0.0	658.	164.1	0.080	0.738	0.0	1.683
801209279	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	200.	MAX CONTINUOUS	0.0	659.	164.8	0.082	0.743	0.0	1.688

Table XIX-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801209129	1.35	0.55	0.31	86.	15.	12.	30.	1454.	147.	0.00169	9.43	1491.	30.	45700.	10.	85.	67.
801209144	1.36	0.53	0.31	86.	15.	12.	31.	1450.	151.	0.00152	9.30	1509.	29.	44080.	5.	67.	71.
801209159	1.37	0.52	0.31	84.	14.	12.	32.	1484.	151.	0.00152	9.38	1540.	29.	43420.	5.	69.	74.
801209174	1.36	0.53	0.31	82.	14.	13.	33.	1500.	152.	0.00138	9.60	1555.	29.	43690.	5.	94.	77.
801209189	1.37	0.52	0.31	82.	14.	13.	33.	1509.	154.	0.00129	9.63	1554.	29.	42690.	3.	99.	83.
801209204	1.53	0.60	0.31	92.	16.	11.	29.	1525.	154.	0.00127	9.66	1602.	28.	43150.	2.	76.	63.
801209219	1.37	0.54	0.31	82.	14.	13.	32.	1518.	154.	0.00123	9.61	1564.	28.	43560.	0.	89.	73.
801209234	1.23	0.54	0.31	73.	14.	14.	32.	1510.	154.	0.00119	9.66	1552.	29.	42100.	0.	106.	91.
801209249	1.56	0.61	0.32	94.	16.	11.	28.	1527.	155.	0.00115	9.14	1555.	28.	44800.	1.	83.	66.
801209264	1.56	0.61	0.32	94.	16.	11.	28.	1537.	155.	0.00112	9.13	1553.	28.	43050.	1.	85.	71.
801209279	1.55	0.61	0.31	94.	16.	11.	28.	1540.	156.	0.00108	9.21	1539.	29.	43370.	2.	79.	65.

Table XIX-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801209129	179.83	99.92	9.	0.51	0.972	1.35	0.60
801209144	193.80	99.93	3.	0.57	0.956	1.35	0.60
801209159	202.49	99.92	3.	0.52	0.946	1.35	0.60
801209174	211.09	99.92	3.	0.53	0.947	1.35	0.60
801209189	227.12	99.92	3.	0.52	0.932	1.35	0.60
801209204	171.14	99.94	3.	0.47	0.932	1.50	0.60
801209219	199.52	99.94	3.	0.49	0.947	1.35	0.60
801209234	247.42	99.93	3.	0.48	0.906	1.20	0.60
801209249	177.09	99.94	3.	0.51	0.948	1.50	0.60
801209264	80.40	99.94	3.	0.49	0.908	1.50	0.60
801209279	173.62	99.93	3.	0.49	0.922	1.50	0.60

Table XX.

RQL combustor parametric data: pressure drop--RESID fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801212131	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	647.	163.7	0.083	0.759	0.0	2.249
801212146	LINER I-F, NOZ AB-H	BP	11.12	0.62	17839.	250.	MAX CONTINUOUS	0.0	649.	163.5	0.082	0.753	0.0	2.236
801212161	LINER I-F, NOZ AB-H	BP	11.00	0.96	17749.	250.	MAX CONTINUOUS	0.0	650.	163.2	0.081	0.761	0.0	2.260
801212176	LINER I-F, NOZ AB-H	BP	10.88	1.29	17660.	250.	MAX CONTINUOUS	0.0	652.	163.2	0.080	0.756	0.0	2.241
801212191	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	657.	162.0	0.083	0.861	0.0	2.325
801212206	LINER I-F, NOZ AB-H	BP	11.12	0.62	17839.	250.	MAX CONTINUOUS	0.0	661.	166.5	0.082	0.842	0.0	2.242
801212221	LINER I-F, NOZ AB-H	BP	11.00	0.97	17747.	250.	MAX CONTINUOUS	0.0	661.	165.8	0.080	0.854	0.0	2.311
801212236	LINER I-F, NOZ AB-H	BP	10.88	1.30	17658.	250.	MAX CONTINUOUS	0.0	660.	165.9	0.080	0.847	0.0	2.253
801212251	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	662.	164.7	0.083	0.942	0.0	2.339
801212266	LINER I-F, NOZ AB-H	BP	11.12	0.62	17839.	250.	MAX CONTINUOUS	0.0	661.	164.9	0.082	0.943	0.0	2.320
801212281	LINER I-F, NOZ AB-H	BP	11.00	0.96	17748.	250.	MAX CONTINUOUS	0.0	663.	164.8	0.081	0.935	0.0	2.277
801212296	LINER I-F, NOZ AB-H	BP	10.88	1.30	17658.	250.	MAX CONTINUOUS	0.0	662.	165.2	0.080	0.925	0.0	2.208
801212311	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	661.	164.3	0.083	0.745	0.0	1.862
801212328	LINER I-F, NOZ AB-H	BP	11.12	0.62	17839.	250.	MAX CONTINUOUS	0.0	661.	164.3	0.082	0.746	0.0	1.845
801212343	LINER I-F, NOZ AB-H	BP	11.00	0.97	17748.	250.	MAX CONTINUOUS	0.0	661.	164.3	0.081	0.743	0.0	1.838
801212359	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	661.	163.4	0.083	0.841	0.0	1.955
801212374	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	662.	163.4	0.083	0.950	0.0	2.126
801212389	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	661.	162.3	0.083	0.758	0.0	1.724
801212404	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	662.	162.2	0.083	0.830	0.0	1.831
801212419	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	661.	162.1	0.084	0.846	0.0	1.832
801212434	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	662.	164.7	0.084	0.852	0.0	2.267
801212449	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	250.	MAX CONTINUOUS	0.0	662.	165.2	0.084	0.768	0.0	1.879
801212464	LINER I-F, NOZ AB-H	BP	10.88	1.30	17658.	250.	MAX CONTINUOUS	0.0	662.	165.5	0.079	0.775	0.0	1.948

Table XX (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
801212479	LINER I-F, NOZ AB-H	BP	10.88	1.30	17659.	250.	MAX CONTINUOUS	0.0	663.	165.7	0.080	0.837	0.0	2.021
801212494	LINER I-F, NOZ AB-H	BP	11.00	0.96	17748.	250.	MAX CONTINUOUS	0.0	663.	165.9	0.081	0.841	0.0	2.003
801212509	LINER I-F, NOZ AB-H	BP	11.12	0.62	17839.	250.	MAX CONTINUOUS	0.0	662.	166.0	0.082	0.837	0.0	1.973
801212539	LINER I-F, NOZ AB-H	BP	11.12	0.62	17839.	250.	MAX CONTINUOUS	0.0	662.	166.2	0.082	0.965	0.0	2.257
801212554	LINER I-F, NOZ AB-H	BP	11.00	0.96	17748.	250.	MAX CONTINUOUS	0.0	661.	166.6	0.081	0.961	0.0	2.219
801212569	LINER I-F, NOZ AB-H	BP	10.88	1.30	17659.	250.	MAX CONTINUOUS	0.0	661.	166.6	0.080	0.952	0.0	2.248

Table XX-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801212131	1.54	0.52	0.32	92.	14.	11.	34.	1516.	154.	0.00150	9.61	1502.	26.	45390.	19.	66.	52.
801212146	1.58	0.53	0.33	93.	14.	11.	33.	1520.	154.	0.00131	9.51	1512.	27.	43780.	2.	59.	48.
801212161	1.59	0.53	0.33	92.	14.	11.	34.	1516.	154.	0.00129	9.71	1526.	26.	43200.	3.	67.	55.
801212176	1.62	0.55	0.33	92.	14.	11.	34.	1520.	154.	0.00142	9.62	1535.	25.	41960.	2.	67.	57.
801212191	1.36	0.50	0.32	80.	13.	13.	35.	1457.	152.	0.00165	10.28	1553.	28.	45720.	3.	86.	68.
801212206	1.40	0.53	0.33	84.	14.	12.	33.	1468.	157.	0.00163	9.60	1562.	27.	45860.	0.	80.	63.
801212221	1.40	0.52	0.32	82.	13.	13.	34.	1470.	156.	0.00173	9.92	1559.	27.	43800.	0.	88.	73.
801212236	1.44	0.54	0.34	83.	14.	12.	33.	1479.	156.	0.00167	9.74	1555.	27.	45440.	0.	84.	67.
801212251	1.24	0.50	0.31	74.	13.	14.	35.	1491.	155.	0.00160	9.56	1554.	28.	43440.	5.	122.	101.
801212266	1.26	0.51	0.32	74.	13.	14.	35.	1500.	155.	0.00160	9.56	1553.	28.	44290.	1.	106.	86.
801212281	1.29	0.53	0.33	74.	14.	14.	34.	1509.	155.	0.00165	9.42	1551.	26.	44320.	0.	109.	69.
801212296	1.32	0.55	0.34	75.	14.	14.	33.	1513.	156.	0.00146	9.18	1550.	26.	44630.	0.	107.	66.
801212311	1.56	0.63	0.32	93.	17.	11.	28.	1527.	156.	0.00142	7.89	1511.	28.	45590.	7.	95.	75.
801212328	1.60	0.65	0.33	93.	17.	11.	28.	1530.	156.	0.00163	7.91	1512.	27.	45650.	2.	91.	72.
801212343	1.62	0.65	0.33	94.	17.	11.	28.	1535.	156.	0.00142	7.85	1510.	26.	45330.	0.	68.	70.
801212359	1.39	0.60	0.31	82.	16.	13.	30.	1507.	155.	0.00173	8.12	1541.	28.	44410.	0.	86.	70.
801212374	1.23	0.55	0.32	72.	14.	14.	32.	1515.	155.	0.00171	8.12	1518.	27.	43140.	0.	104.	87.
801212389	1.55	0.68	0.31	90.	18.	11.	26.	1472.	156.	0.00169	6.57	1487.	29.	43400.	0.	85.	71.
801212404	1.41	0.64	0.31	82.	17.	13.	28.	1469.	156.	0.00169	6.31	1530.	27.	43970.	0.	81.	67.
801212419	1.39	0.64	0.32	81.	17.	13.	28.	1473.	156.	0.00169	6.27	1537.	27.	44230.	1.	84.	68.
801212434	1.38	0.52	0.32	82.	14.	13.	34.	1497.	155.	0.00167	9.81	1553.	26.	42590.	0.	73.	62.
801212449	1.53	0.63	0.32	91.	16.	11.	28.	1501.	157.	0.00163	8.24	1506.	25.	44460.	0.	76.	62.
801212464	1.57	0.62	0.32	90.	16.	11.	29.	1474.	157.	0.00171	8.39	1512.	25.	43280.	1.	73.	61.

Table XX-A (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
801212479	1.46	0.60	0.32	84.	15.	12.	30.	1494.	158.	0.00169	7.95	1539.	26.	43850.	1.	74.	61.
801212494	1.43	0.60	0.32	83.	16.	12.	30.	1492.	158.	0.00171	8.01	1549.	26.	43850.	0.	72.	59.
801212509	1.42	0.60	0.32	84.	16.	12.	29.	1512.	158.	0.00177	7.93	1540.	26.	44390.	0.	78.	63.
801212539	1.23	0.52	0.32	73.	14.	14.	34.	1495.	158.	0.00179	8.24	1531.	26.	43900.	0.	100.	83.
801212554	1.25	0.54	0.32	73.	14.	14.	33.	1504.	158.	0.00179	8.16	1532.	26.	44790.	0.	95.	77.
801212569	1.28	0.54	0.33	74.	14.	14.	33.	1505.	159.	0.00177	8.00	1529.	26.	43600.	0.	95.	79.

Table XX-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801212131	137.47	99.91	11.	0.52	0.951	1.50	0.60
801212146	54.34	99.94	9.	0.53	0.895	1.50	0.60
801212161	39.70	99.94	3.	0.53	0.877	1.50	0.60
801212176	30.14	99.94	3.	0.52	0.834	1.50	0.60
801212191	181.09	99.93	7.	0.63	0.968	1.35	0.60
801212206	70.22	99.94	3.	0.61	0.938	1.35	0.60
801212221	52.63	99.94	3.	0.60	0.902	1.35	0.60
801212236	34.91	99.94	3.	0.59	0.903	1.35	0.60
801212251	274.26	99.91	7.	0.52	0.934	1.20	0.60
801212266	99.06	99.93	3.	0.50	0.931	1.20	0.60
801212281	64.02	99.93	3.	0.50	0.903	1.20	0.60
801212296	44.63	99.94	3.	0.49	0.879	1.20	0.60
801212311	198.29	99.92	8.	0.56	0.959	1.50	0.60
801212328	80.63	99.94	3.	0.55	0.933	1.50	0.60
801212343	49.71	99.94	3.	0.55	0.914	1.50	0.60

Table XX-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
801212359	188.58	99.94	8.	0.57	0.954	1.35	0.60
801212374	230.58	99.93	9.	0.49	0.909	1.20	0.60
801212389	190.32	99.94	8.	0.70	0.925	1.50	0.60
801212404	179.18	99.94	8.	0.71	0.940	1.35	0.60
801212419	182.60	99.94	7.	0.67	0.939	1.20	0.60
801212434	164.45	99.95	3.	0.48	0.898	1.35	0.60
801212449	163.56	99.95	3.	0.57	0.937	1.50	0.60
801212464	33.17	99.94	3.	0.59	0.898	1.50	0.60
801212479	33.20	99.94	7.	0.51	0.906	1.35	0.60
801212494	43.75	99.95	3.	0.52	0.916	1.35	0.60
801212509	72.57	99.94	3.	0.51	0.932	1.35	0.60
801212539	95.68	99.94	8.	0.51	0.929	1.20	0.60
801212554	55.89	99.94	3.	0.49	0.922	1.20	0.60
801212569	42.45	99.94	3.	0.49	0.888	1.20	0.60

Table XXI.

RQL combustor parametric data: residence time--RESID fuel.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
810109133	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONTINUOUS	0.0	643.	165.5	0.082	0.768	0.0	2.234
810109148	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONTINUOUS	0.0	651.	164.4	0.082	0.651	0.0	2.311
810109163	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONTINUOUS	0.0	652.	164.3	0.082	0.950	0.0	2.294
810109178	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+15%WA	0.0	666.	164.4	0.097	0.867	0.0	2.403
810109193	LINER I-F, NOZ AB-H	BP	11.13	0.58	17851.	--	MAX CONT+15%WA	0.0	666.	164.2	0.096	0.848	0.0	2.390
810109208	LINER I-F, NOZ AB-H	BP	11.13	0.58	17851.	--	MAX CONT+15%WA	0.0	664.	164.2	0.096	0.977	0.0	2.500
810109223	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+15%WA	0.0	664.	163.9	0.097	0.974	0.0	2.515
810109238	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+15%WA	0.0	665.	165.4	0.096	1.054	0.0	2.540
810109253	LINER I-F, NOZ AB-H	BP	11.13	0.58	17851.	--	MAX CONT+15%WA	0.0	664.	165.4	0.095	1.063	0.0	2.486
810109268	LINER I-F, NOZ AB-H	BP	11.13	0.58	17851.	--	MAX CONT+15%WA	0.0	663.	165.4	0.096	0.890	0.0	2.276
810109283	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+15%WA	0.0	663.	165.3	0.097	0.878	0.0	2.303
810109298	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+15%WA	0.0	663.	165.4	0.096	0.995	0.0	2.298
810109313	LINER I-F, NOZ AB-H	BP	11.13	0.58	17851.	--	MAX CONT+15%WA	0.0	663.	165.7	0.095	0.974	0.0	2.297
810109328	LINER I-F, NOZ AB-H	BP	11.13	0.57	17852.	--	MAX CONT+15%WA	0.0	662.	164.3	0.097	1.034	0.0	2.280
810109343	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+15%WA	0.0	660.	164.2	0.096	1.027	0.0	2.293
810109358	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+30%WA	0.0	663.	166.5	0.107	0.977	0.0	2.484
810109373	LINER I-F, NOZ AB-H	BP	11.14	0.55	17858.	--	MAX CONT+30%WA	0.0	663.	166.7	0.105	0.978	0.0	2.448
810109388	LINER I-F, NOZ AB-H	BP	11.14	0.55	17858.	--	MAX CONT+30%WA	0.0	663.	166.9	0.105	1.069	0.0	2.498
810109403	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+30%WA	0.0	665.	164.6	0.107	1.039	0.0	2.429
810109418	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+30%WA	0.0	665.	164.7	0.107	0.976	0.0	2.155
810109433	LINER I-F, NOZ AB-H	BP	11.14	0.55	17858.	--	MAX CONT+30%WA	0.0	666.	164.5	0.105	0.976	0.0	2.102
810109448	LINER I-F, NOZ AB-H	BP	11.14	0.55	17858.	--	MAX CONT+30%WA	0.0	665.	164.9	0.105	1.042	0.0	2.302
810109463	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONT+30%WA	0.0	665.	165.4	0.107	1.051	0.0	2.204

Table XXI (Cont)

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
810109478	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONTINUOUS	0.0	658.	166.6	0.082	0.787	0.0	2.077
810109501	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	MAX CONTINUOUS	0.0	656.	167.3	0.082	0.660	0.0	2.012
810109516	LINER I-F, NOZ AB-H	BP	11.12	0.63	17837.	--	MAX CONTINUOUS	0.0	654.	167.3	0.082	0.647	0.0	1.989

Table XXI-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
810109133	1.50	0.50	0.31	93.	14.	11.	34.	1510.	156.	0.00271	9.78	1465.	28.	44590.	24.	59.	49.
810109148	1.36	0.50	0.31	82.	13.	13.	34.	1516.	155.	0.00303	9.82	1518.	28.	45920.	16.	92.	74.
810109163	1.22	0.50	0.31	73.	14.	14.	34.	1504.	155.	0.00326	9.66	1528.	28.	47970.	15.	137.	106.
810109178	1.57	0.57	0.31	80.	13.	13.	36.	1538.	155.	0.00280	9.24	1425.	31.	50040.	11.	92.	68.
810109193	1.62	0.58	0.32	82.	13.	13.	36.	1547.	155.	0.00288	8.85	1410.	31.	57130.	10.	99.	64.
810109208	1.41	0.55	0.32	71.	12.	15.	38.	1542.	155.	0.00301	9.46	1475.	29.	51860.	11.	92.	65.
810109223	1.40	0.54	0.32	71.	12.	15.	38.	1535.	154.	0.00286	9.41	1517.	29.	50300.	11.	89.	66.
810109238	1.29	0.53	0.31	66.	12.	16.	38.	1561.	156.	0.00278	9.57	1527.	31.	47810.	13.	107.	62.
810109253	1.29	0.55	0.32	66.	12.	16.	37.	1565.	156.	0.00278	9.72	1533.	29.	49340.	12.	100.	74.
810109268	1.55	0.61	0.32	79.	14.	13.	34.	1535.	156.	0.00278	9.61	1448.	29.	51320.	12.	67.	63.
810109283	1.55	0.59	0.31	79.	13.	13.	34.	1523.	156.	0.00278	9.37	1445.	29.	51150.	12.	86.	62.
810109298	1.36	0.59	0.31	70.	13.	15.	34.	1521.	156.	0.00276	9.73	1503.	29.	53370.	12.	91.	62.
810109313	1.41	0.60	0.32	72.	13.	14.	34.	1523.	156.	0.00276	9.29	1526.	28.	50370.	12.	89.	65.
810109328	1.35	0.61	0.32	67.	13.	15.	34.	1584.	155.	0.00274	9.25	1555.	28.	49940.	10.	98.	72.
810109343	1.32	0.59	0.31	67.	13.	15.	34.	1577.	155.	0.00282	9.11	1549.	28.	49260.	9.	92.	69.
810109358	1.53	0.60	0.31	72.	13.	14.	37.	1584.	157.	0.00274	9.41	1415.	35.	47750.	7.	98.	76.
810109373	1.55	0.62	0.32	72.	13.	14.	36.	1594.	157.	0.00278	9.42	1412.	35.	48590.	7.	103.	78.
810109388	1.41	0.60	0.32	66.	12.	16.	37.	1590.	157.	0.00276	9.74	1475.	31.	50000.	8.	92.	68.
810109403	1.45	0.62	0.31	67.	13.	15.	37.	1576.	155.	0.00271	9.35	1541.	34.	47130.	10.	90.	70.
810109418	1.54	0.70	0.31	71.	14.	15.	32.	1599.	155.	0.00284	9.50	1399.	36.	45400.	9.	96.	78.
810109433	1.55	0.72	0.32	71.	15.	15.	32.	1599.	155.	0.00282	9.52	1412.	36.	48170.	8.	109.	83.
810109448	1.45	0.66	0.32	67.	13.	15.	35.	1597.	155.	0.00276	9.38	1493.	36.	50530.	8.	103.	75.
810109463	1.43	0.68	0.32	66.	14.	16.	33.	1602.	156.	0.00278	9.51	1495.	34.	49960.	8.	98.	72.

Table XXIA (Cont)

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
810109478	1.46	0.55	0.31	90.	15.	12.	31.	1542.	156.	0.00282	10.34	1520.	27.	43710.	6.	66.	55.
810109501	1.75	0.57	0.31	108.	16.	10.	30.	1564.	158.	0.00282	9.65	1452.	26.	46530.	5.	63.	50.
810109516	1.83	0.60	0.32	110.	16.	9.	29.	1587.	158.	0.00274	9.25	1411.	26.	45150.	6.	73.	60.

Table XXI-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
810109133	133.38	99.90	1.	0.47	0.971	1.50	0.60
810109148	203.23	99.90	1.	0.44	1.002	1.35	0.60
810109163	289.74	99.90	1.	0.52	1.042	1.20	0.60
810109178	183.80	99.92	1.	0.51	1.084	1.50	0.50
810109193	79.11	99.93	1.	0.52	1.212	1.50	0.50
810109208	79.82	99.92	1.	0.52	1.078	1.35	0.50
810109223	173.92	99.92	1.	0.55	1.062	1.35	0.50
810109238	223.59	99.91	1.	0.51	1.035	1.20	0.50
810109253	92.21	99.92	1.	0.51	1.044	1.20	0.50
810109268	77.30	99.92	1.	0.57	1.079	1.50	0.60
810109283	166.68	99.92	1.	0.59	1.096	1.50	0.60
810109298	167.17	99.92	1.	0.65	1.139	1.35	0.60
810109313	78.99	99.92	1.	0.62	1.050	1.35	0.60

Table XXI-B (Cont)

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
810109328	88.45	99.92	1.	0.50	1.032	1.20	0.60
810109343	183.97	99.92	1.	0.46	1.048	1.20	0.60
810109358	204.94	99.92	1.	0.43	1.030	1.50	0.50
810109373	101.88	99.92	1.	0.42	1.030	1.50	0.50
810109388	87.02	99.93	1.	0.47	1.041	1.40	0.50
810109403	192.38	99.91	1.	0.43	1.025	1.40	0.50
810109418	209.12	99.91	1.	0.43	0.973	1.50	0.60
810109433	107.63	99.91	1.	0.44	1.012	1.50	0.60
810109448	96.29	99.92	1.	0.47	1.055	1.40	0.60
810109463	188.12	99.92	1.	0.42	1.031	1.40	0.60
810109478	147.32	99.93	1.	0.49	0.931	1.50	0.60
810109501	135.27	99.94	1.	0.40	1.002	1.60	0.60
810109516	66.58	99.93	1.	0.42	0.934	1.60	0.60

Table XXII.

RQL combustor performance data: idle--ERBS, RESID, SRC-II fuels.

READING NUMBER	HARDWARE CONFIGURATION	FUEL TYPE	FUEL %H	FUEL %N	FUEL LHV	FUEL TEMP (F)	SIMULATED ENGINE POWER CONDITION	W NOZ (LB/S) (IF AIR ASSIST)	TINLET (F)	PINLET (PSIA)	W FUEL P (LB/S)	W AIR P (LB/S)	W FUEL S (LB/S)	W AIR S (LB/S)
810112116	LINER I-F, NOZ AB-H	A	12.88	0.01	18327.	--	IDLE	0.0	330.	51.4	0.011	0.150	0.0	0.938
810112131	LINER I-F, NOZ AB-H	A	12.88	0.01	18327.	--	IDLE	0.0	330.	51.5	0.012	0.151	0.0	0.888
810112146	LINER I-F, NOZ AB-H	A	12.88	0.01	18327.	--	IDLE	0.0	331.	51.4	0.011	0.155	0.0	0.787
810113116	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	IDLE	0.0	355.	51.5	0.012	0.150	0.0	0.921
810113131	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	IDLE	0.0	356.	51.5	0.012	0.148	0.0	0.891
810113146	LINER I-F, NOZ AB-H	B	11.24	0.27	17933.	--	IDLE	0.0	357.	51.5	0.013	0.153	0.0	0.786
810112176	LINER I-F, NOZ AB-H	C	6.71	13.32	14453.	--	IDLE	0.0	335.	53.8	0.012	0.154	0.0	0.927
810112191	LINER I-F, NOZ AB-H	C	6.71	13.32	14453.	--	IDLE	0.0	338.	53.7	0.012	0.150	0.0	0.904
810112206	LINER I-F, NOZ AB-H	C	6.71	13.32	14453.	--	IDLE	0.0	340.	53.9	0.013	0.152	0.0	0.797

Table XXII-A

READING NUMBER	PRIMARY (RICH ZONE) EQUIVALENCE RATIO	SECONDARY (LEAN ZONE) EQUIVALENCE RATIO	OVERALL EQUIVALENCE RATIO	PRIMARY RES. TIME (MSEC.)	SECONDARY RES. TIME (MSEC.)	PRIMARY REF. VELOCITY (FT/S)	SECONDARY REF. VELOCITY (FT/S)	EXIT TEMPERATURE (F)	EXIT PRESSURE (PSIA)	SPECIFIC HUMIDITY	COMBUSTOR DELTA P (PSI)	LINER TEMPERATURE (F)	CO (PPM)	CO2 (PPM)	HC (PPM)	NOX (PPM)	NOX (PPMC)
810112116	1.11	0.18	0.10	203.	14.	5.	32.	519.	49.	0.00021	2.21	1089.	36.	15150.	53.	67.	[illegible]
810112131	1.16	0.20	0.10	202.	15.	5.	30.	566.	49.	0.00021	2.25	1085.	43.	15910.	34.	102.	225.
810112146	1.05	0.21	0.09	196.	17.	5.	27.	522.	49.	0.00023	2.37	1029.	34.	15660.	29.	80.	192.
810113116	1.17	0.19	0.10	199.	14.	5.	32.	483.	49.	0.00127	2.27	953.	24.	13180.	20.	50.	137.
810113131	1.19	0.20	0.10	201.	15.	5.	31.	499.	49.	0.00129	2.22	967.	25.	13410.	19.	52.	139.
810113146	1.17	0.23	0.10	195.	17.	5.	28.	500.	49.	0.00129	2.39	942.	24.	13640.	18.	52.	135.
[illegible]	1.05	0.17	0.09	212.	15.	5.	30.	448.	51.	0.00056	2.26	929.	23.	14190.	27.	113.	261.
810112191	1.05	0.17	0.09	217.	16.	5.	30.	428.	52.	0.00056	2.13	892.	22.	13650.	24.	106.	274.
810112206	1.12	0.21	0.10	214.	18.	5.	26.	465.	52.	0.00056	2.19	916.	23.	14660.	22.	115.	276.

Table XXII-B

READING NUMBER	% N CONVERSION	COMBUSTION EFFICIENCY (%)	SMOKE NUMBER	PATTERN FACTOR	FARR	DESIRED PRIMARY ZONE EQUIVALENCE RATIO	DESIRED LEAN ZONE EQUIVALENCE RATIO
810112116	0.0	99.42	1.	1.49	1.121	1.36	0.19
810112131	0.0	99.56	1.	1.23	1.094	1.31	0.20
810112146	0.0	99.63	1.	1.65	1.165	1.22	0.21
810113116	--	99.70	1.	1.94	0.854	1.33	0.19
810113131	--	99.71	1.	1.91	0.870	1.28	0.19
810113146	--	99.73	1.	1.72	0.869	1.19	0.20
810112176	48.53	99.60	1.	1.68	0.922	1.28	0.18
810112191	49.42	99.62	1.	2.16	0.925	1.23	0.19
810112206	45.04	99.65	1.	2.14	0.89	1.15	0.20

REFERENCES

1. Lister, E., Niedzwiecki, R. W., and Nichols, L., "Low NO_x Heavy Fuel Combustor Program," ASME Paper 80-GT-69, 1980, Gas Turbine Conference, New Orleans.

2. "Standards of Performance for New Stationary Sources, Gas Turbines," Federal Register, 40 CFR Part 60, Environmental Protection Agency, 10 September 1979, pp. 52792-52807.

3. Troth, D. L., "Investigation of Aircraft Gas Turbine Combustor Having Low Mass Emissions," ASME 74-GT-36, 1974 Gas Turbine Conference, Zurich, Switzerland.

4. Verdouw, A. J., "Evaluation of a Staged Fuel Combustor for Turboprop Engines," ASME-76-WA/GT-5, 1976, Winter Annual Meeting, New York.

5. Pierce, R. M., Smith, C. E., and Hinton, B. S., "Low NO_x Combustor Development for Stationary Gas Turbine Engines," Proceedings of the Third Stationary Source Combustion Symposium EPA-600/7-79-050C Vol. III, February 1979.

6. Martin, F. J., and Dederick, P. K., "NO_x from Fuel Nitrogen in Two-Stage Combustion," Sixteenth Symposium (International) on Combustion, 1976.

7. Takagi, T., Tatsumi, T., and Ogasawara, M., "Nitric Oxide Formation from Fuel Nitrogen in Staged Combustion: Roles of HCN and NH_i," Combustion and Flame, 35 (1979).

8. Ballal, D. R., and Lefebvre, A. H., "Combustion Efficiency of Gas Turbine Burning Alternate Fuels," AIAA/SAE 14th Propulsion Conference, Paper No. 78-1000.

9. Longwell, J. P., et al., "Flame Stabilization by Bluff Bodies and Turbulent Flames in Ducts," Fourth Symposium (International) on Combustion, Williams and Wilkins, 1953, pp 90-97.

10. Williams, G. C., et al., "Flame Stabilization and Propagation in High Velocity Gas Streams," Third Symposium on Combustion Flame and Explosion Phenomena, Williams & Wilkins, 1949.

11. Longwell, J. P., et al., "Flame Stabilization by Baffles in a High Velocity Gas Stream," Third Symposium on Combustion Flame and Explosion, Williams & Wilkins, 1949.

12. Herbert, M. V., "A Theoretical Analysis of Reaction Rate Controlled System: Part II," Eighth Symposium (International) on Combustion, Williams & Wilkins, 1962.

13. Design and Development of Gas Turbine Combustors, Northern Research and Engineering Corporation, NREC Report 1344-1, 1980.

14. DDA internal memo.

15. Spadaccini, L. J., "Autoignition Characteristics of Hydrocarbon Fuels at Elevated Temperatures and Pressures," ASME Paper No. 76-GT-3, 1976.

16. Prok, G. M., and Seng, G. T., "Initial Characterization of an Experimental Referee Broadened-Specification (ERBS) Aviation Turbine Fuel," NASA TM 81440, January 1980.

17. Gleason, C. C., Oller, T. L., Shayeson, M. W., and Bahr, O. W., "Evaluation of Fuel Character Effects on J79 Engine Combustion System," final report for contract F33615-77-C-2042, June 1979.

18. Vogel, R. E., Troth, D. L., and Verdouw, A. J., "Fuel Character Effects on Current, High Pressure Ratio, Can-Type Combustion Systems," final report for contract F33615-78-C-2006, April 1980.

19. "Aircraft Gas Turbine Engine Exhaust Smoke Measurement, Aerospace Recommended Practice 1179," May 1970.

20. Schirmer, R. M., and Quigg, H. T., "High Pressure Combustor Studies of Flame Radiation as Related to Hydrocarbon Structure," Phillips Petroleum Co. Report 3952-65R, Bartlesville, 1965.

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13. ABSTRACT ***(Maximum 200 words)***
The purpose of this program was to develop the "dry" technology required to operate an industrial gas turbine combustion system on minimally processed, heavy petroleum or residual fuels having high levels of fuel-bound nitrogen (FBN) while producing acceptable levels of exhaust emissions. Also, a combustor utilizing this technology was to be fabricated and tested to demonstrate fuel flexibility and low exhaust emissions in a combustor rig test. For this program Detroit Diesel Allison (DDA) chose its Model 570-K industrial gas turbine engine as the candidate engine to receive this technology. Three fuels were supplied for the combustor test demonstrations: a typical middle distillate fuel represented by the Experimental Referee Broad Specification (ERBS) fuel, a heavy residual fuel, and a synthetic fuel represented by a coal derived liquid SRC-II (Solvent Refined Coal) fuel. Three combustor concepts were designed and fabricated to achieve fuel flexibility with low exhaust emissions. The primary concept was an air staged, variable-geometry combustor designed to produce low emissions from fuels having high levels of FBN. This combustor used a long residence time, fuel-rich primary combustion zone followed by a quick-quench air mixer to rapidly dilute the fuel rich products for the fuel-lean final burnout of the fuel. This combustor, called the Rich/Quench/Lean (RQL) combustor, was extensively tested using each fuel over the entire power range of the Model 570-K engine. Also, a series of parametric tests was conducted to determine the combustor's sensitivity to rich-zone equivalence ratio, lean-zone equivalence ratio, rich-zone residence time, and overall system pressure drop. The RQL combustor was very successful in achieving program goals. Minimum nitrogen oxide emissions (NO_x) were measured at 50 to 55 ppmv at maximum continuous power for all three fuels. Smoke was less than a 10 SAE smoke number.

14. SUBJECT TERMS
Gas turbine engines; Combustors; Fuels; Exhaust emissions; Fuel bound nitrogen; Low NO_x

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